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ESBC

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COVER: *Agapostemon sp.* (Hymenoptera: Halictidae)

A female *Agapostemon* (probably *texanus*) gathers nectar from a diffuse knapweed flowerhead. Halictine bees run that gamut from true eusociality to solitary nesters and are as such an excellent system for studying the evolution of hymenopteran social behaviour. *Agapostemon* species can be communal nesters, but *A. texanus* as a species seems to be pretty steadfastly solitary in its habits. Like other ground nesting bees, it has an annual life cycle where overwintering females emerge in the warm part of the spring, build vertical burrows in soil and provision individual eggs with a pollen ball to support larval development all the way through to pupation. Males become abundant in late summer and fall and mated females will overwinter in diapause to start the cycle over the following year. Unlike the bee, which is native, diffuse knapweed is an invasive pest in western rangelands.

Photograph details:
Photograph by Robert Lalonde (UBC Okanagan). Made with a Canon EOS digital rebel T2i equipped with a Canon 100mm f2.8 macro lens in natural light; ISO 800; f8 at 1/250 sec; on 8 July 2013 at 1557h on the UBC Okanagan campus in Kelowna, British Columbia.

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FORUM

The new Checklist of British Columbia Lepidoptera and how it came to be

GREGORY R. POHL[1] and ROBERT A. CANNINGS[2]

The Entomological Society of British Columbia (ESBC) is publishing a new checklist of the Lepidoptera of British Columbia as the third volume in the ESBC's Occasional Papers series (Pohl et al., in press). Occasional Paper No. 1, published in 1951, was "An annotated check list of the macrolepidoptera of British Columbia" by J. R. J. Llewellyn Jones. Llewellyn Jones was an active ESBC member who willed some of his estate to the Society so that insect lists and other projects might be published for the good of British Columbia (B.C.) entomology. It is an appropriate and historic gesture for the ESBC to publish the next major list of British Columbia moth and butterfly species more than 60 years later. The 1951 list proved to be a significant entomological milestone and we are convinced that ours will be an influential one, too. The list's authors are Greg Pohl (Natural Resources Canada, Northern Forestry Centre, Edmonton, AB), Rob Cannings (Royal British Columbia Museum [RBCM], Victoria, B.C.), Jean-François Landry (Agriculture and Agri-Food Canada, Canadian National Collection of Insects, Arachnids and Nematodes [CNC], Ottawa, ON), David Holden (Canadian Food Inspection Agency, Burnaby, B.C.), and Geoff Scudder (University of British Columbia [UBC], Vancouver, B.C.).

The list documents 2,757 Lepidoptera species reported for B.C. The data are based on literature records and examination of the major public insect collections in the province and the CNC. The classification and nomenclature follow the most recent phylogenetic hypotheses for the order, and captures nomenclatural changes to the end of September 2013. We include records from relevant literature published since 1950 and from selected older works, such as previous B.C. checklists and significant taxonomic revisions. The list supplies taxonomic, distributional and biological notes for selected species; we list an additional 30 species that probably occur in B.C. and consider 126 species to be introduced from outside North America. Also included is a list of 294 species erroneously reported from B.C. in previous works: this important section of the manuscript clears up previous misidentifications and errors, many of which have persisted in the literature for decades. Introductory sections give an overview of the order, review the ecozones of the province, and discuss the history of lepidopterology in B.C. and our current state of knowledge. We review each of the 68 families occurring in B.C., providing information on distinguishing features, biology and diversity. An index to the higher taxonomic names, genera, species and common names is included.

Species lists such as this answer the fundamental question: "What lives here?" As a foundation for other biological research, such lists are the first step on a continuum of exploration into what these species do and how they interact with other species. The new B.C. Lepidoptera checklist will be a significant and useful resource for anyone studying the Lepidoptera of the province, including resource and conservation managers, biodiversity researchers, taxonomists, naturalists and amateur collectors. Although other lists have been published on portions of the butterfly and moth fauna, none is as comprehensive as this one, which represents a major step forward in our understanding of the Lepidoptera fauna of the province.

The list had its beginnings as something else entirely. In the late 1990s, Geoff Scudder and Rob and Syd Cannings embarked on a

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project to produce online overviews and user-friendly, illustrated identification keys to about 505 insect families and 29 insect orders in B.C. Launi Lucas, Geoff's assistant at UBC, coordinated much of the project, drew illustrations, and prepared the material for the Internet. For several years, the "Insect Families of British Columbia" project was funded by Forest Renewal B.C. and its subsequent incarnations (Forest Innovation Investment and the Forest Science Program). Initially, the project results were posted on a website hosted by the Zoology Department at UBC, but by 2007 this had migrated to *E-Fauna BC* to form core entomological content there.

Geoff and Rob created the initial draft of the Lepidoptera list so that they could write a brief summary of the diversity of each BC moth and butterfly family for the "Insect Families of B.C." Don Lafontaine of the CNC provided the original species list in 2005. By 2007, the Lepidoptera account was complete and posted on the Internet (Cannings and Scudder 2007a, 2007b).

In 2009, Greg Pohl brought his expertise and experience on Lepidoptera to the list. Beginning with a submission of additional micromoth names, Greg's involvement grew and he eventually became the list's coordinator. He delved deeply into literature and collection records to produce a more comprehensive treatment, with greater taxonomic detail and updated nomenclature. His contribution was critical, as he had already been amassing species names, collection details, literature, and other important data on B.C. moths, especially micromoths, as part of ongoing research on the western Canadian fauna. To add more expertise in micromoths and to link the list more firmly to the national data, Jean-François Landry joined the team in 2012. A year later, David Holden also became an author, bringing considerable B.C. experience and knowledge to the project. The additional authority these participants offered was immense: about 450 species were added to the 2007 list, and the knowledge of many of their colleagues was incorporated into the data.

The challenge of compiling the information was straightforward but daunting: to extract records of Lepidoptera that may occur in B.C. from all relevant taxonomic publications, and from specimens in public collections with significant B.C. holdings. Butterfly information was largely based upon the definitive works by Layberry et al. (1998), Guppy and Shepard (2001) and Pyle (2002). For macromoths, we drew upon Troubridge and Lafontaine's *Moths of Canada* website (CBIF 2003) and various fascicles in the *Moths of North America* series, but have also examined virtually all North American taxonomic works published since 1950 and many from before. For micromoths, we checked almost every North American taxonomic publication since 1900, and a few earlier ones. All these literature records were then augmented with previous provincial lists, regional lists and specimen data from the RBCM, the Beaty Biodiversity collection at UBC, the Canadian Forest Service–Pacific Forestry Centre collection, the CNC in Ottawa, and several other regional collections across Canada. Some curators were able to provide species lists for us; we visited other collections to extract the records ourselves. Most of this was done over several years by Greg, with assistance from summer student Christi Jaeger. As well, Rémi Hébert, Scientific Project Coordinator for the General Status of Species in Canada (Environment Canada), stepped in with critical funds for contracts to extract records from some large historical monographs and from specimens in the UBC collection and the CNC. All these activities brought together the vast majority of the required data. To produce the current list, we compiled all the records organised by a nomenclatural database built by Greg from the taxonomic papers examined. We then ground-truthed the list by flagging questionable records and by checking the identities of selected specimens. The resulting list was examined by a number of experts and then vetted again by anonymous reviewers for the *Journal of the ESBC*.

Greg and Rob wrote an introduction putting the contents of the list in biological, geographical, historical and taxonomic contexts. An overview of the Lepidoptera was excerpted from the order account that Rob had prepared for the material now online on *E-Fauna BC*. Rob also wrote a summary of the ecozones of B.C. as an overview of the province's environment. Greg summarized the history and current state of Lepidoptera

research in B.C. and described the format and content of the checklist. He also prepared the index, the reference section, and the list of excluded taxa.

As authors of the list, we are primarily compilers and editors of scattered information; we owe a huge debt to the curators of our public collections and the taxonomists who described and revised all the species listed. We also acknowledge historical workers such as George W. Taylor, E. M. Anderson, Ernest H. Blackmore and James R. J. Llewellyn Jones, as well as more recent researchers and collectors such as Libby Avis, Cris Guppy, Dean Nicholson, Jon Shepard and Jeremy deWaard. This list would not exist without their efforts.

Our intent is to make a PDF of the complete list available on the ESBC and RBCM websites and on *E-Fauna BC*. We have a large spreadsheet of literature records and collection holdings that formed the basis of the species list, and we also hope to make that available online. We encourage users of the list to verify uncertain entries and to look for gaps and omissions that will motivate them to survey poorly known habitats and discover new records. Dave Holden[3] will compile additions and corrections to the list and will disseminate future updated versions.

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Ground beetle (Coleoptera: Carabidae) assemblages in the Conservation Reserve Program crop rotation systems in interior Alaska

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ABSTRACT

To improve knowledge of ground beetle communities and the influence of habitat succession on these communities in Alaska, adult ground beetle (Coleoptera: Carabidae) activity and diversity were documented on Conservation Research Program (CRP) agricultural lands in Delta Junction, Alaska (64° N, 145° W). Twenty species, comprising a total sample of 6,116 specimens, were collected during 2006 and 2007 from plots that were in the CRP for 9 years (young-field plots) and 19 years (old-field plots). Two species, *Cymindis cribricollis* Dejean and *Amara obesa* Say, are reported for the first time for Alaska. Species richness of carabids for our study plots was estimated, using the Chao 1 and Chao 2 estimators (Chao 1987), to be 22 and 28 species, respectively. Ninety-four percent of the specimens belonged to five species: *Pterostichus adstrictus* Eschscholtz (42.9%), *Agonum cupreum* Dejean (17.9%), *Calathus ingratus* Dejean (15%), *Amara obesa* (11.1%), and *Dicheirotrichus cognatus* (Gyllenhaal) (7.1%). Only *Ag. cupreum* showed significant effects based on plot age, with 7.5 times more specimens caught on younger plots. The majority of carabid activity occurred late in the season, from mid-September to early October. A comparison of our findings with historical data (1943–1956) from the collection of the Matanuska Experiment Station, in Palmer, Alaska, indicates that only three of the 44 carabid species from the historic Palmer collection are among the CRP fauna sampled.

Key Words: Alaska, beneficial, Carabidae, CRP, diversity

INTRODUCTION

Little is known about the beneficial insect fauna associated with Alaska's agricultural or natural systems (Hagerty *et al.* 2009). Given anticipated expansion of agriculture in Alaska and current trends in climate change, which is most pronounced in northern latitudes (Serreze *et al.* 2000; Chapin *et al.* 2006; Chen *et al.* 2011), it is important to establish baseline knowledge of the state's insect fauna from which subsequent comparisons can be made. Ground beetles (Coleoptera: Carabidae) have been used as ecological indicators for many years (Pearce and Venier 2006; Menalled *et al.* 2007; Work *et al.* 2008) and are also known predators of agricultural pests and seeds of weed plants (Lövei and Sunderland 1996; Kromp 1999; Harrison and Regnier 2003; O'Neal *et al.* 2005; Harrison and Gallandt 2012). Alaskan farmers have enrolled more than 10,000 hectares under the National Resources Conservation Service (NRCS 2003), Conservation Reserve Program (CRP), most of which is located near the city of Delta Junction to control erosion by wind (Schoephorster 1973; Lewis *et al.* 1979). Conservation Reserve Program land in other states has been positively correlated with wildlife diversity, including butterflies

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(Davros *et al.* 2006), birds (Johnson and Schwartz 1993; Millenbah *et al.* 1996; Best *et al.* 1997; Delisle and Savidge 1997), mammals (Chapman and Ribic 2002), and herptiles (Semlitsch and Bodie 2003).

The Conservation Reserve Program promotes the conservation of habitats beneficial to wildlife (NRCS 2003). However, participation in the CRP programs requires that CRP fields be mown every two to three years to slow succession to shrubs and trees (Seefeldt *et al.* 2010). Agricultural practices are known to affect the presence, activity, and abundance of ground beetles in agricultural settings (O'Rourke *et al.* 2008; Ward *et al.* 2011). However, despite the long history of CRP in Alaska (Seefeldt *et al.* 2010), little is known about the effects of CRP-management practices on ground beetles in the state. Additionally, due to the state's large size, remoteness, vast regions of roadless lands, and historic dearth of in-state entomological professionals, the insect fauna of Alaska is one of the most poorly documented in the US (Sailer 1954).

Few detailed descriptions of entire, extant carabid assemblages in Alaska exist. These include Lindroth's (1963) description of the carabids of the Aleutian Islands and studies on the carabid fauna of Kodiak Island (Ball 1969; Lindroth 1969b; Lindroth and Ball 1969). Most of the detailed assemblage descriptions are checklists, often lacking within-state locality or ecological data. The earliest Alaskan records are known from Russian coleopterist Mannerheim (1843, 1846, 1852, 1853). When Hamilton (1894) summarized the beetle fauna of Alaska, he reported 43 carabid species now considered valid. Schwarz (1900) of the Harriman Expedition reported 28 now-valid species. As part of an environmental impact statement prior to the planned, but later aborted, detonation of a multi-megatonne nuclear device, Watson *et al.* (1966) documented 19 species of carabids from the Cape Thompson region of Alaska. The most thorough treatments of the family for Alaska, including Canada, is the classic six-volume work by Lindroth (1969a). Bousquet (1991) listed 231 Alaskan species, and Bousquet and Larochelle (1993), listed 234 species. An excellent summary of the carabidae of the Yukon, which lists 209 species and includes syntheses of biogeographic and habitat data, was prepared by Ball and Currie (1997). However, these more recent synthetic works, from Lindroth (1969a) to Ball and Currie (1997), summarize data across vast regions rather than describe restricted assemblages as we do here.

This research was initiated to study the species composition, seasonal activity, and effects of plot age on dominant carabid species in CRP lands in Delta Junction, Alaska, and to aid state-wide efforts to document Alaska's entomofauna.

MATERIALS AND METHODS

Study Site. Land registered under the CRP near Delta Junction, Alaska, (64° N, 145° W) was surveyed for ground beetles. Eight plots were selected based on their time under the CRP program (Table 1). Plots were assigned to two age groups, with four plots per group according to the plot history under CRP management that Seefeldt *et al.* (2010) describe. Plots with nine years under the CRP program were grouped as young plots, while plots with 19 years under CRP management were considered old plots. Older plots have more disturbance events over time (mowing and weed control): this was expected to reduce the relative abundance of carabids.

The Seefeldt *et al.* (2010) report was also used to assign a litter cover to each plot (Table 1) and compare those parameters to relative ground beetle species' frequencies. Plots are located in the Interior Bottomlands Ecoregion of the Alaska boreal forest (Gallant *et al.* 1995), adjacent to the outwash plain of the Tanana River. The area ranges in elevation from 330 to 385 m; soils are silt loam (NRCS 2013). Surrounding forest vegetation is a mix of white and black spruce [*Picea glauca* (Moench) Voss and *P. mariana* (Mill.) Britton, Sterns & Poggenburg], balsam poplar (*Populus balsamifera* L.), quaking aspen (*Populus tremuloides* Michx.), and paper birch (*Betula papyrifera* Marsh.), with associated understorey species (Hulten 1968). Average winter temperature are between –2 and –4 °C, with frost-free periods typically lasting 80 to 120 days. The average July temperature is about 16 °C. Annual precipitation varies from

Table 1
Eight study plots near Delta Junction, Alaska, USA, on Conservation Research Program land.

Plot Number	Latitude	Longitude[a]	CPR time[b]	Area	Litter Depth (ha)(cm)[c]
11	63°59.203'N	145°18.940'W	old	44.33	73
15	63°58.710'N	145°20.100'W	old	54.85	70
25	63°58.058'N	145°08.221'W	young	36.18	83
26	63°57.925'N	145°08.480'W	young	36.18	76
27	63°57.454'N	145°10.154'W	old	44.60	80
33	64°00.391'N	145°07.040'W	old	46.22	73
37	64°01.883'N	145°07.265'W	young	63.36	73
39	64°01.276'N	145°07.727'W	young	21.50	87

[a] Geo-coordinates have a precision of +/– 150 m (WGS84 datum); elevation of all plots: 330–350 m.
[b] Years under CRP: old = 19 years; young = 9 years.
[c] Litter depts. As per Seefeldt *et al.* (2010).

250 to 300 mm. The study area was cleared from 1979 to 1982 as part of Delta Agricultural Projects (Lewis *et al.* 1979). Fields are farmed on a three-year rotation, with two years of spring barley or oats followed with one year of tilled fallow (Seefeldt *et al.* 2010).

Trap Methods. Insects were collected using pitfall traps, which are a standard method used to measure ground beetle activity density in both agricultural and natural systems (Southwood 1978; O'Rourke *et al.* 2008; Ward *et al.* 2011). Although often interpreted as measures of relative abundance, pitfall trap catches more accurately measure activity density and have been criticized for their demonstrable limitations and biases (e.g., Topping and Sunderland 1992; Melbourne 1999). Pitfall traps consisted of two plastic 480 ml containers (10.5 cm diameter X 7.5 cm deep), one inside the other. Holes were dug with a standard hand-held post-hole digger, and containers were placed in each hole so that the rim of the inner container was flush with the ground. The outer container had holes in the bottom to allow drainage. The inner container was filled approximately one-quarter full with a solution of 25 % propylene glycol. Each trap was covered with a white 23-cm-diametre plastic plate. Plates were held in place by three landscaping staples pushed through the top. The traps were placed in the field in a diamond pattern (approx. 1 m between each trap), using five traps within each of the eight plots, for a total of 40 traps. Traps were deployed as early as holes could be dug to set traps.

Insect counts from the five traps per site and sampling date were combined and considered as a sample for statistical analysis. Based on relative plant density, traps were placed in plot areas that seemed representative of the overall plot. Traps were emptied and reset on a weekly basis in 2006 and 2007. Sampling dates were 6 June to 20 October 2006 and 8 May to 28 September 2007. At times, voles were caught in traps.

Sample Processing. Samples were transported to the US Department of Agriculture (USDA), Agricultural Research Service (ARS) laboratory on the University of Alaska–Fairbanks campus and processed. Ground beetles were pinned and identified primarily by the third author, using methods described by Lindroth (1969a), Bousquet and Larochelle (1993), and Ball and Bousquet (2001). Most identifications were confirmed by George E. Ball (University of Alberta,

Canada), Robert Davidson (Carnegie Museum of Natural History, Pittsburg, Pennsylvania), and Christopher J. Marshall (Oregon State Arthropod Collection, Corvallis, Oregon). Voucher specimens were deposited in the insect collection of the University of Alaska Museum (UAM), Fairbanks, Alaska. Records of these specimens are available online via the UAM database (Arctos 2013a). Species names follow the classification of Bousquet and Larochelle (1993), and Ball and Bousquet (2001).

Species Richness. EstimateS v8.2 (Colwell 2009) was used to calculate estimated species richness using nine estimators. Species-richness estimators allow one to extrapolate beyond one's data to infer the total number of species in these plots if sampling were continued using the same methods, thus providing an estimate of completeness. The results over the combined two-year sample for two of the most frequently used estimators, Chao 1 and Chao 2, were calculated (Chao 1987). Chao 1 is an abundance-based estimator, in that it uses the number of species represented by one or two individuals, whereas Chao 2 is an incidence-based estimator, in that it relies on the number of species found in only one or two sample units, regardless of the number of individuals (Chazdon *et al.* 1998).

Data Analysis. The number of insects per trap per 14-day period was calculated by combining weekly captures and used to present seasonal variation. Insect counts from the five traps per site were pooled for statistical analysis. Insect counts for species for which at least 50 specimens were collected during the two-year sampling period (O'Rourke *et al.* 2008) were analyzed using PROC GLIMIX (SAS 2008), and means were compared with the LSMEANS statement with the ILINK option. The Poisson distribution was used to model the counts, the Generalized Chi-square/DF was used to test fitness, and the Type III Tests of Fixed Effects were used to test significance for time under CRP.

Historic Data. The University of Alaska Museum Insect Collection (UAM) was examined to provide additional information on ground beetle species in Alaska. This collection, formerly housed at the Matanuska Experiment Station of the University of Alaska Agricultural and Forestry Experiment Station in Palmer, Alaska, is the only large agricultural insect collection maintained in the state (Washburn 1972). Some of the carabid records of the collection were published previously (Lindroth 1969a) and all of the species have been reported from the state by other workers. However, because this collection was assembled as part of early agricultural research in Alaska, we report the Alaskan records here for comparative purposes. Specimen data for these records are available via UAM's online database (Arctos 2013b). The majority of specimens housed in the UAM Insect Collection were previously identified by J. M. Valentine and C. H. Lindroth in the 1940s and 1960s, respectively.

RESULTS

Species Richness. A total of 6,116 specimens representing 20 species from 14 genera were collected (Table 2). The full set of estimators (±1 SD) yielded estimates that ranged from 19.7 to 28 species (Fig. 1): 22.8 (ACE); 23.8 ± 0.01 (ICE); 22.3 ± 3.4 (Chao 1); 28 ± 11.7 (Chao 2); 23.9 ± 1.9 (Jack 1); 26.8 (Jack 2); 21.7 (Bootstrap mean); 19.7 (MMRuns Mean); 20 (Cole Rarefaction; Colwell, 2009).

Activity Density. The total number of specimens from CRP plots was almost equal between years, with 3,099 and 3,017 specimens for 2006 and 2007, respectively (Table 2). However, *A. cupreum* specimens were 3.2 times more abundant in 2007 (n=828) than in 2006 (n=256), and *A. obesa* activity was 15.3 times higher in 2006 (n=644) than in 2007 (n=42). Ninety-four percent of the specimens belong to five species: *P. adstrictus* (42.9%), *A. cupreum* (17.9%), *C. ingratus* (15%), *A. obesa* (11.1%), and *D. cognatus* (7.1%). Two species, *A. obesa* and *C. cribricollis*, represent new records for Alaska.

A single species, *P. adstrictus*, was the predominant species in both years, representing 39.3% and 46.4% of total specimens collected during 2006 and 2007, respectively (Table 2). This species was captured equally in all plots, regardless of time under CRP management or litter depth

(Table 1). *P. adstrictus* was also the most abundant species in the historic data (Arctos, 2013b), with 58 specimens (Table 3).

Ground beetle activity density differed by the amount of time the plot had been under the CRP program, but was not affected by the depth of the litter cover on plots. However, the response varied by species (Table 1 and 4). All species with at least 50 specimens in each year in the total dataset were found in both old and young plots, but not in equal proportions. A significantly lower number (7.5 times less) of *A. cupreum* was recorded for plots with a long history (19 years) under the CRP

Table 2

Activity densities of 20 ground beetle species, for which at least 50 specimens were collected during the two-year sampling period from CRP land, sorted from most to least abundant. Percent within yearly totals and sums across both years are presented. Delta Junction, Alaska, USA, 2006–2007.

Species	%2006	%2007	Sum
Pterostichus adstrictus Eschscholtz	39.3	46.4	2616
Agonum cupreum Dejean	8.3	27.4	1084
Calathus ingratus Dejean	19.1	10.8	920
Amara obesa Say[a]	20.8	1.4	686
Dicherotrichus cognatus (Gyllenhaal)	8.1	6.1	435
Amara sp(p.)[b]	1.1	2.6	112
Carabus chamissonis Fischer	1	2.1	92
Asaphidion yukonense Wickham	0.4	1.3	52
Cymindis cribricollis Dejean[a]	0.7	0.5	37
Cicindela longilabris Say	0.7	0.5	35
Carabus vietinghoffii Adams	0.1	0.3	13
Bembidion sp.	<0.1	0.3	9
Miscodera arctica (Paykull)	0.1	0.2	8
Harpalus laticeps LeConte	0.2	<0.1	6
Notiophilus semistriatus Say	<0.1	<0.1	3
Amara hyperobrea Dejean	<0.1	<0.1	2
Syntomus americanus (Dejean)	0	0.1	2
Harplaus fulvilabris Mannerheim	<0.1	0	1
Harpalus sonnulentus Dejean	0	<0.1	1
Pterostichus kotzebuei Ball	0	<0.1	1

n = 3099 and 3017 individuals for 2006 and 2007, respectively.

[a] New record for Alaska

[b] *Amara* sp(p.) confirmed as not *Amara obesa*

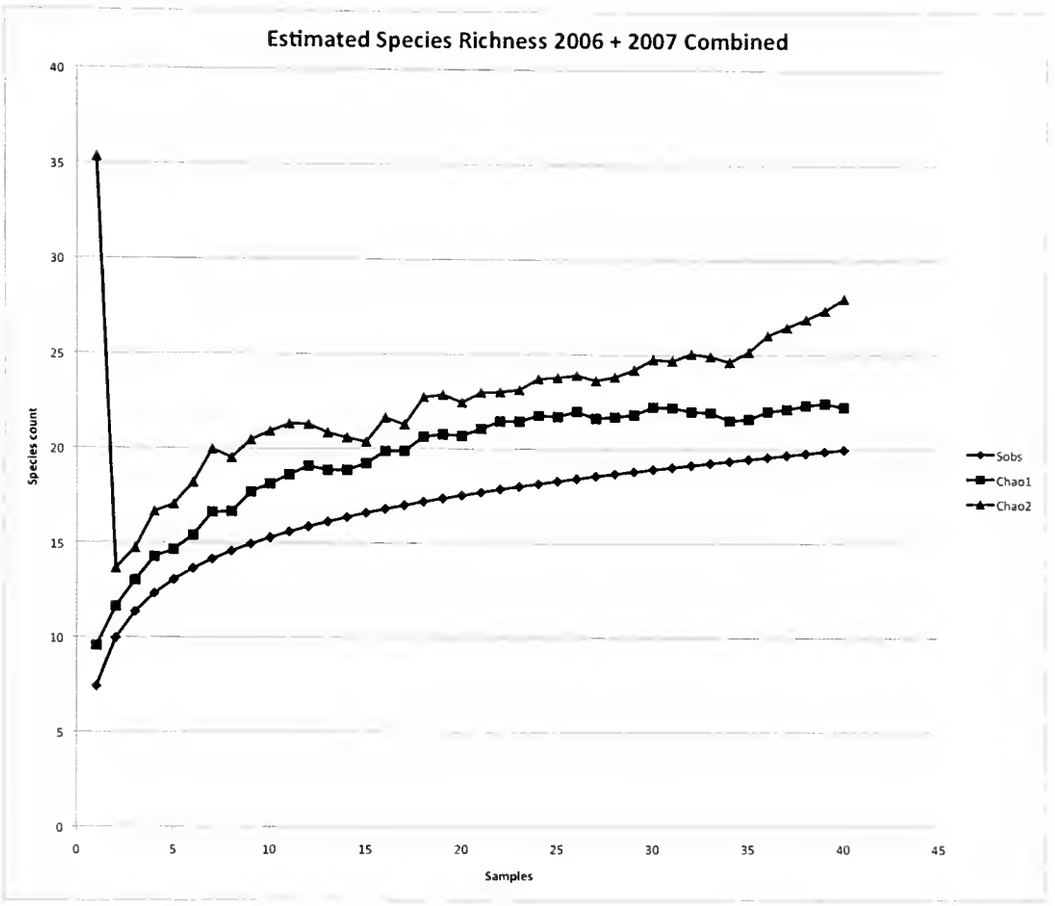

Figure 1. Carabid species richness estimates calculated using the Chao 1 and 2 estimators (Chao 1987) for combined 2006 and 2007 samples, from Delta Junction, AK, CRP land. At Sample 40, the means of each estimator were 22, 25, and 28, respectively. The observed species richness was 20 species obtained by Sample 27. Estimates were made using EstimateS v8.2 (Colwell 2009).

management, compared to plots with a mean of nine years under CRP (Table 4). However, frequencies of *A. obesa*, *C. ingratus*, *D. cognatus*, and *P. adstrictus* were not significantly affected by time under CRP management.

The maximum activity density observed was 32.9 *P. adstrictus* per 14-day sampling period for October 15, 2007. *Pterostichus adstrictus* was collected after first snowfall and can be active until early October. In 2006, snow/rain was registered as early as September 25, snow was registered by September 30, and insects were collected up to October 30 (Fig. 2).

Activity was observed from May to October (Fig 2). Traps were deployed as early as holes could be dug to set traps. During both years, ground beetles were active during the first week after traps were deployed, before the soils thawed. Depending on the year and species, ground beetle activity, as measured by the mean number of adults per 14-day period, started increasing rapidly in late September (2006) or late August (2007).

Historic Data. The UAM holdings from the Experiment Station, in Palmer, Alaska, which were assembled as an agricultural research collection, includes 44 confidently identified carabid species (Table 3). Three species occur in both the historic data and the CRP findings (*P. adstrictus*, *C. ingratus*, and *D. cognatus*). Phenology data from the historic sampling shows three peaks of activity, with both early (April 3) and late (November 17) records (Fig. 3).

DISCUSSION

Species Richness. The majority of estimators predict species richness close to our observation of 20, although some estimators, like the Chao2, indicate the fauna could be much richer than we sampled. The species-accumulation curve (Fig. 1) does not reach an asymptote, suggesting additional species in the community remain unsampled. The large

Table 3

Forty-four carabid species, based on 254 Alaskan specimens with confident determinations collected primarily by R. H. Washburn, G. W. Gasser, and J. C. Chamberlin between 1943 and 1956, held in the UAM Insect Collection, and formerly housed at the Matanuska Experiment Station of the University of Alaska Agricultural and Forestry Experiment Station, in Palmer, Alaska, USA. Specimen determinations were made primarily by C. H. Lindroth and J. M. Valentine. Specimen data available online via the UAM database (Arctos 2013b). Species sorted by number of specimens.

Species	No. specimens	Species	No. specimens
Pterostichus adstrictus Eschscholtz [a]	58	*Carabus taedatus* Fabricius	2
Amara patruelis Dejean	49	*Pterostichus empetricola* (Dejean)	2
Amara interstitialis (Dejean)	22	*Sericoda quadripunctata* (DeGeer)	2
Scaphinotus marginatus (Fischer von Waldheim)	11	*Amara littoralis* Mannerheim	1
Amara laevipennis Kirby	10	*Amara sinuosa* (Casey)	1
Calathus ingratus Dejean [a]	9	*Amara torrida* (Panzer)	1
Amara quenseli (Schonherr)	8	*Bembidion castum* Casey	1
Dicheirotrichus cognatus (Gyllenhaal) [a]	8	*Bembidion lapponicum* Zetterstedt	1
Harpalus somnulentus Dejean	8	*Bembidion mutatum* Gemminger & Harold	1
Amara erraticus (Duftschmid)	7	*Bembidion nigripes* (Kirby)	1
Agonum consimile (Gyllenhaal)	5	*Elaphrus clairvillei* Kirby	1
Amara lunicollis Schiodte	5	*Elaphrus purpurans* Hausen	1
Bembidion incertum (Motschulsky)	4	*Harpalus fuscipalpis* Sturm	1
Bradycellus nigrinus (Dejean)	4	*Loricera pilicornis* (Fabricius)	1
Elaphrus riparius Linneaus	4	*Nebria metallica* Fischer von Waldheim	1
Bembidion levettei Casey	3	*Nebria sahlbergii* Fischer von Waldheim	1
Elaphrus trossulus Semenov	3	*Opisthius richardsoni* Kirby	1
Pterostichus crenicollis LeConte	3	*Pterostichus castaneus* (Dejean)	1
Acalathus advena (LeConte)	2	*Pterostichus oregonus* LeConte	1
Bembidion binaculatum (Kirby)	2	*Pterostichus pinguedineus* Eschscholtz	1
Bembidion grapii Gyllenhaal	2	*Sericoda bembidioides* Kirby	1
Bembidion obscurellum (Motschulsky)	2	*Sericoda bogemannii* (Gyllenhaal)	1

[a] Also collected from CPR field studies

Table 4

Mean number of ground beetles (±SE) with at least 50 specimens per year, in plots with different time under CRP management (years under CRP: old = 19 years; young = 9 years). Delta Junction, Alaska, USA, 2006–2007.

	Species				
	Ag. cupreum	*Am. obesa*	*C. ingratus*	*D. cognatus*	*P. adstrictus*
Young	6.0±0.9	4.6±1.2	4.4±1.0	1.8±0.5	7.6±4.4
Old	0.8±0.2	0.3±0.1	1.2±0.2	0.9±0.3	7.6±4.4
F value	12.18	6.45	0.89	0.84	0.00
P	0.0246	0.0707	0.4043	0.4325	0.9999
DF (Num/Den)	1 / 4.05	1 / 3.64	1 / 3.58	1 / 2.97	1 / 3.91

number of species with small counts (Table 2) also indicates sampling of this fauna is incomplete. Because these plots are not isolated habitats, a low number of "tourist" species, which pass through but do not breed or spend much time in the sampled habitats, are expected. However, the intent of this study was to document the dominant carabid species, which these estimators indicate we have done.

New State Records. Both of the two species, *A. obesa* and *C. cribricollis*, that are new records for Alaska are reported from all three major northwestern Canadian jurisdictions (YK, NT, BC) by Bousquet (1991), so their presence in interior Alaska is not surprising. Bousquet and Larochelle (1993) list *C. cribricollis*, but not *A. obesa*, as previously reported from Alaska, but based on doubtful record(s) that need verification.

Amara obesa is reported to prefer dry, usually sandy, soil with sparse vegetation (Larochelle and Lariviere 2003). This species was the fourth most abundant, with 686 specimens collected. Ninety-four percent of these specimens were collected in 2006.

Cymindis cribricollis is a similarly xerophilous species collected mainly from dry, sandy moraines with sparse or absent plant cover (Lindroth 1969a; Ball and Currie 1997; Larochelle and Lariviere 2003). In our study, 36 *C. cribricollis* specimens were collected, 75% of which were from two sandy plots where little vegetation other than moss was present; the other 25% of the specimens collected were from a plot with sandy soils and sparse bushes, mostly covered by grass. Our results agree with previously published accounts of this species' habitat associations. It is unknown how widespread this species is distributed in the state. Given that the agriculture-associated collecting done in interior Alaska by the USDA station in Palmer during the mid-1900s sampled less than 20% of the state's carabid fauna (Table 3), these two species' status as new records for Alaska is probably an artifact of past under-sampling rather than natural range expansions or human introductions. Nevertheless, it is perplexing that *A. obesa* was so common in our 2006 samples in a region of the state easily accessed by collectors, and yet had remained previously undetected.

Trophic Classifications. The top five most active species (Table 4) are all exclusively predators, with the exception of *D. cognatus*, which is also known to feed on seeds (*Calluna* in Europe), and is thus also granivorous (Larochelle and Lariviere 2003). These species are recorded as known predators of flies (*Ag. cupreum*), lepidopteran larvae (*Ag. cupreum*, *C. ingratus*, and *P. adstrictus*), lepidopteran eggs (*D. cognatus* and *P. adstrictus*), sawfly pupae, dipteran eggs, and elaterids (*P. adstrictus*), and grasshopper eggs and nymphs (*Am. obesa*) (Larochelle and Lariviere 2003).

Activity Density. The high capture rate of one species, *P. adstrictus*, is not uncommon. O'Rourke *et al.* (2008) and Hajeck *et al.* (2007) reported dominant carabid species in studies from Iowa and New York, respectively. *Pterostichus adstrictus* is a habitat generalist, and is found from lowlands to alpine zones,

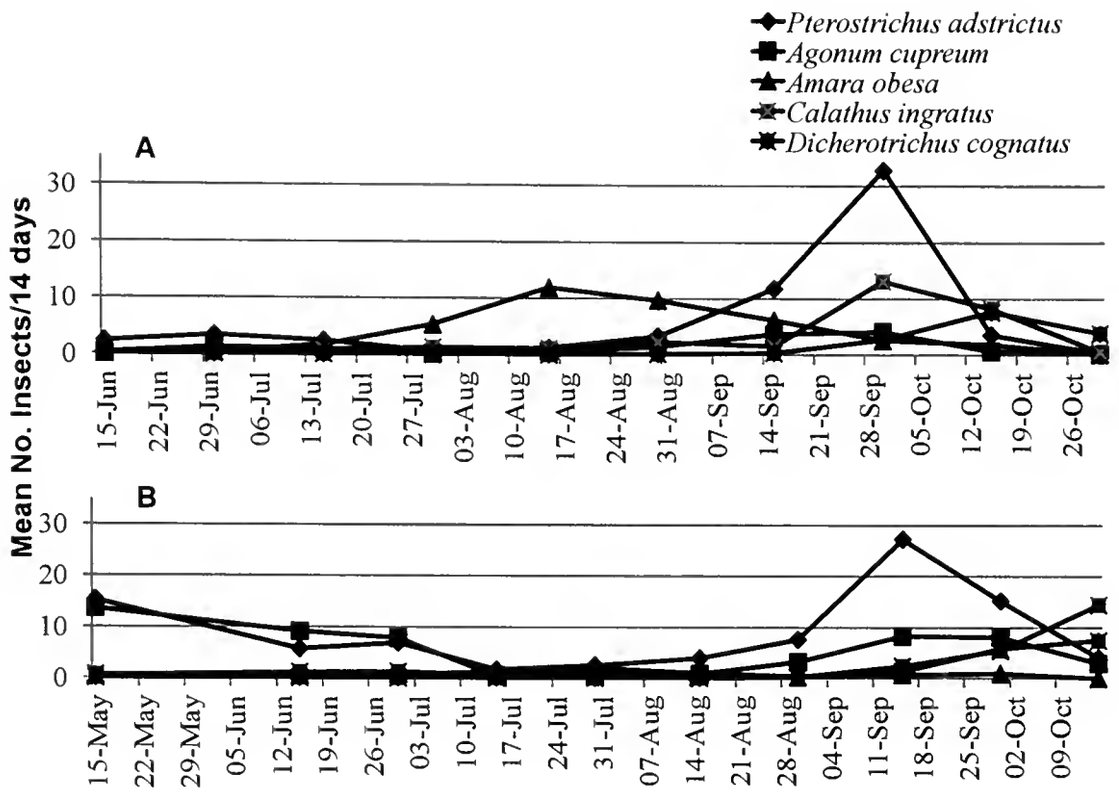

Figure 2. Mean number of *P. adstrictus*, *Ag. cupreum*, *Am. obesa*, *C. ingratus*, and *D. cognatus* per 14-day period, CRP land, Delta Junction, Alaska, USA, 2006 (A) and 2007 (B).

interior forests, grasslands, and coastal zones (Larochelle and Lariviere 2003).

Conservation Reserve Program plots were mowed in 2006 (Seefeldt *et al.* 2010), which might have affected insect relative densities such as the observation that more than three times more *A. cupreum* specimens were collected in 2007 than in 2006. O'Rourke *et al.* (2008) and Hajek *et al.* (2007) reported strong yearly variation in ground beetle populations from disturbed areas in Iowa and New York, respectively. French *et al.* (1998) reported large differences in ground beetle abundances between years, most likely due to differences in rainfall. However, this year- to-year variation is not unusual in Alaska: leafhoppers (Pantoja *et al.* 2009), moths (Landolt *et al.* 2007), click beetles (Pantoja *et al.* 2010a, b), and aphids (Pantoja *et al.* 2010c) displayed significant year-to-year variation in different areas of Alaska, including Delta Junction. The differences in ground beetles' adult-activity densities could not be explained with current knowledge of the biology of this group in the state, but might be associated with relative plant types in the plots. Some carabids are known to consume weed seed (Toft and Bilde 2002; Ward *et al.* 2011), and population size and presence is affected by agronomic practices and the seed bank in natural and managed ecosystems (Menalled *et al.* 2007). Seefeldt *et al.* (2010) reported an increase in plant diversity and increased density of shrubs with increased time in the CRP in Alaska. Ground beetle activity might be affected by reduced grass seed as the shrub densities increase in the plots. However, plant diversity increased at a rate of about two species per 1000 m2 per year (Seefeldt *et al.* 2010), and effects of plant successions on seed bank will not immediately be seen in insect densities. Research is needed to study the possible effects of mowing, plant density, and seed bank on carabid relative densities in subarctic Alaska. Additional research is also needed to understand the components of ground beetles' diets in Alaska CRP lands and to elucidate the possible influence of CRP management practices on their abundance.

Effects on ground beetle abundance by plot variables such as time in the CRP program (Table 4) varied by species. Gobbi and Fontaneto (2008) suggest that the effects of human intervention on ground beetle species' richness are species dependent. O'Rourke *et al.* (2008) elaborated on the possibility of manipulating habitat for carabid diversity and preservation.

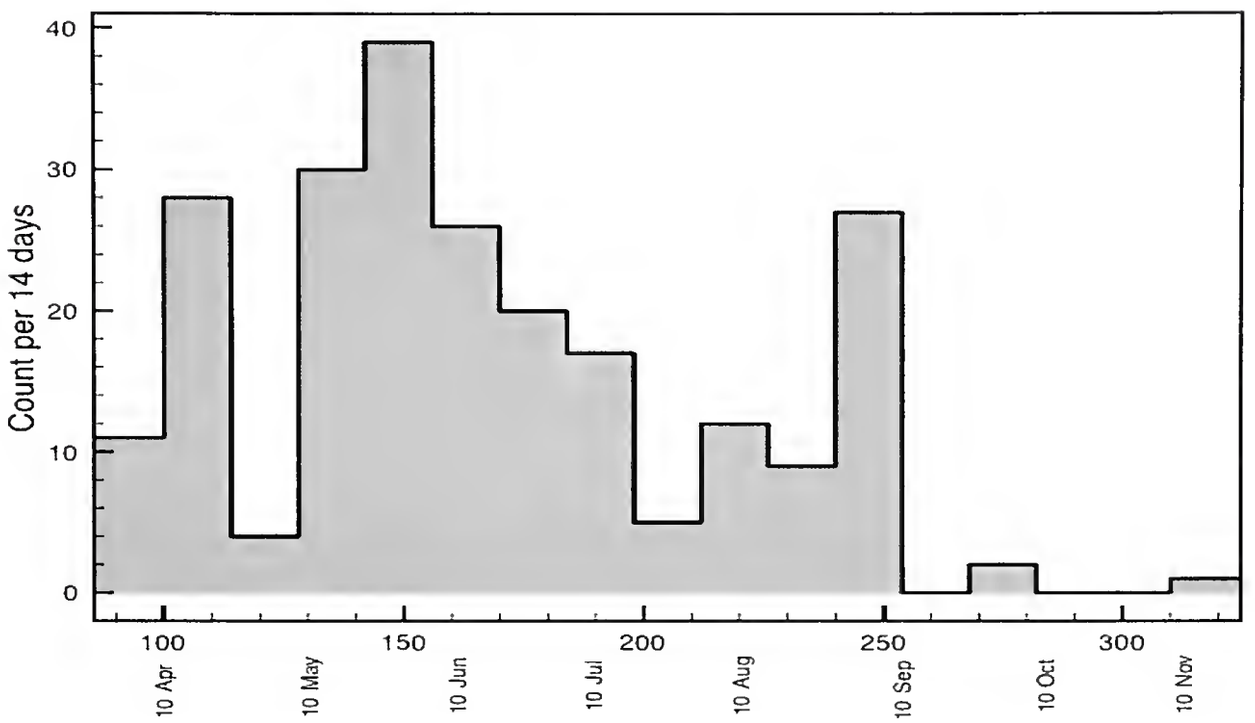

Figure 3. Phenology of Palmer, Alaska, carabidae. Total counts of all carabid species from historic sample (Table 3), with date data (n = 231 specimens) aggregated into 14-day periods from the earliest date across all years.

Late-seasonal adult activity, as we have found for the most abundant species of the CRP sites (Fig. 2) and the historic data (Fig. 3), has been associated with carabid species that overwinter as adults (Hajek *et al.* 2007; Ward *et al.* 2011). In Iowa, carabids were captured until late September, but peak activity was recorded from early June to late July (O'Rourke *et al.* 2008). Our data suggest that mowing CRP plots should occur early in the season, when carabids are less active (Fig. 2).

Historic Data. Only three of the 44 carabid species from the historic Palmer collection are among the sampled CRP fauna. This may seem surprising; however, the entire state's fauna includes more than 240 carabid species, making the lack of shared species among these small samples less remarkable. Not surprisingly, these three species are among the eight most abundant species of the historic dataset. At least *Am. laevipennis* and *Sc. marginatus*, which were also among the top eight most abundant in the historic data, are understandably absent from the CRP data, because these species are known only from south of the Alaska Range. The CRP study site is north of the Alaska Range. *Scaphinotus marginatus* is abundantly collected along the Alaskan coast from the southeast of the state through the Aleutian chain.

To our knowledge, this is the first report on species composition and population dynamics of ground beetles in interior Alaska, and specifically from CRP lands. Information on ground beetles' geographic distribution, population dynamics, dispersal, and biology is needed to understand their roles as predators and seed consumers in natural systems. This study provides some of the information necessary to guide future research in subjects such as species composition, seasonality, a framework for sampling, and time to mow fields. Additional research is needed to study the ecology of the dominant species and their relationships with soil type and CRP management practices, including the pest species on which they are assumed to prey.

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Diagnostic molecular markers to detect and identify primary parasitoids (Hymenoptera: Braconidae) of *Ericaphis fimbriata* on highbush blueberry

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ABSTRACT

The objective of this research was to develop diagnostic molecular markers for detecting and identifying the most common primary parasitoids of *Ericaphis fimbriata* (Richards) (Hemiptera: Aphididae), which is an important vector of *Blueberry scorch virus* (BlScV) on highbush blueberry *Vaccinium corymbosum* L. (Ericales: Ericaceae) in southwestern British Columbia. Mitochondrial cytochrome c oxidase subunit I gene (COI) sequences and specific reverse primers for the parasitoids *Aphidius ericaphidis* Pike and Starý, *Ephedrus incompletus* Provencher, and *Praon unicum* Smith (Hymenoptera: Braconidae) were developed. The combination of three primers in a multiplex polymerase chain reaction (PCR) assay detected and differentiated DNA from adults of all three parasitoid species. When individual field-collected aphids were challenged with the multiplex PCR assay, immatures of the two numerically dominant parasitoid species, *A. ericaphidis* and *P. unicum*, were readily detected, as was multiparasitism by these two species. The uncommon parasitoid species, *E. incompletus*, was detected less frequently by multiplex PCR assay than by rearing from the aphid hosts.

The diagnostic molecular markers are useful tools for estimating of rates of parasitism and for identifying immatures of parasitoid species within aphid hosts, particularly if used in combination with rearing and dissection assays of field-collected aphids.

Key Words: aphids; parasitoids; mtDNA; COI; multiplex PCR; multiparasitism

INTRODUCTION

Hymenopteran parasitoids attack the dominant colonizing aphid, *Ericaphis fimbriata* (Richards) (Hemiptera: Aphididae), on highbush blueberry, *Vaccinium corymbosum* L. (Ericales: Ericaceae) in the Pacific Northwest (Raworth *et al.* 2008). The two primary parasitoid species most frequently reared from *E. fimbriata* on highbush blueberry in British Columbia (B.C.) are *Praon unicum* Smith and a recently described species previously known as *Aphidius* n. sp. (Raworth *et al.* 2008), now identified as *Aphidius ericaphidis* Pike and Starý (Pike *et al.* 2011). Other primary parasitoids in the genera *Aphidius*, *Praon*, and *Ephedrus* were less frequently reared from *E. fimbriata* in B.C. (Raworth *et al.* 2008); those in the latter genus have since been identified as *E. incompletus* Provencher (Mathur and Pike, unpublished data). All these parasitoids are in the family Braconidae.

Ericaphis fimbriata transmits *Blueberry scorch virus* (BlScV), which causes substantial crop loss (Bristow *et al.* 2000). The primary parasitoids by themselves do not significantly reduce *E. fimbriata* populations on highbush blueberry, but they are part of a broader community of predators and pathogens (Mathur *et al.* unpublished data), which, if conserved, might slow the transmission of BlScV by reducing populations of its main vector. Future studies of the role and impact of primary parasitoids within the community of natural enemies would be facilitated by diagnostic molecular markers that detect parasitoid DNA within

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aphids collected from the field. As noted by Gariepy *et al.* (2007), molecular methods supplement but do not replace traditional rearing and dissection techniques for detecting parasitoids in hosts.

Here we report the development of diagnostic molecular markers that can be used to detect and identify the most common primary parasitoids of *E. fimbriata* on highbush blueberry. Sequence diversity in the mitochondrial cytochrome c oxidase subunit I gene (COI; Hebert *et al.* 2003) was used to develop specific primers for *A. ericaphidis*, *E. incompletus*, and *P. unicum*. Primers for each species were combined in a specific multiplex PCR assay capable of detecting simultaneously the three species of parasitoids. The accuracy of the multiplex assay was validated by sampling a local population of *E. fimbriata* on highbush blueberry and comparing the percentage of collected aphids from which primary parasitoids emerged with the percentage of parasitized aphids detected by PCR.

MATERIALS AND METHODS

Development of specific primers for singleplex and multiplex PCR assays

Adult *A. ericaphidis*, *E. incompletus*, and *P. unicum* that were preserved in 95% ethanol were obtained during field surveys in the Pacific Northwest during 2005 and 2006 (Raworth *et al.* 2008). Genomic DNA was isolated from individual parasitoids with a DNeasy tissue kit® (QIAGEN Inc., Mississauga, ON) using the manufacturer's protocol. Individuals were air-dried to remove ethanol and then homogenized using a disposable microtube pestle (Mandel Scientific Company Inc., Guelph, ON) in the extraction buffer provided with the kit. DNA was eluted in 50 µl of buffer and stored at –80 °C for further use.

The COI region of mitochondrial DNA from individuals was amplified by PCR using the universal insect primer set, LCO 1490 (5'GGTCAACAAATCATAAAGATATTGG) and HCO 2198 (5'TAAACTTCAGGGTGACCAAAAAATCA) (Folmer *et al.* 1994). The PCR mixture (50 µl) contained 1x PCR buffer solution (GeneSys Ltd., Medicorp Inc., Montreal, QC), 0.2 mM of dNTPs, 0.2 µM of each universal primer, 1.25 U of Taq DNA polymerase (GeneSys Ltd., Medicorp Inc., Montreal, QC) and 30–50 ng of DNA template. DNA amplification was performed using a thermal cycler (iCycler, Bio-Rad Laboratories, Mississauga, ON). The temperature regime for all PCR reactions was 94°C for 2 min, followed by 35 cycles of 94°C for 30 s, 50°C for 45 s, 72°C for 60 s, and a final extension step of 72°C for 7 min. PCR products were visualized on 1.5% agarose gels stained with GelRed (Biotium Inc., Hayward, CA, USA) and purified with the QIAquick® PCR purification kit (Qiagen Inc., Mississauga, ON). Sequencing of the COI regions was done by the Nucleic Acid and Protein Synthesis Unit (NAPS) at the University of British Columbia (Vancouver, B.C.) using an Applied Biosystem sequencer and the universal primers described above. Polymerase chain reaction products from 13–37 individuals of each parasitoid species were sequenced to check for sequence variability. All sequences were confirmed by sequencing in both directions.

Specific reverse primers were designed for *A. ericaphidis*, *E. incompletus* and *P. unicum* from the regions of the COI gene that were conserved within species but variable among species (Table 1). These primer sequences were evaluated for suitable base composition,

Table 1

Primers used in singleplex and multiplex PCR assays

Primer	Sequence
Reverse *A. ericaphidis*	5' GTCATTACCAATTAACCTACCAGA 3'
Reverse *E. incompletus*	5' GGAAAAGCTATATCTGAACCACC 3'
Reverse *P. unicum*	5' CAGAAATTCCTCTATGTCCAGAA 3'

annealing temperature, and self-compatibility using the on-line software, Primer3 (Rozen and Skaletsky 2000). Primers were synthesized by Integrated DNA Technologies (Coralville, IA, USA). These primers were evaluated for PCR specificity using DNA from 13–37 individuals from *A. ericaphidis*, *E. incompletus* and *P. unicum*. Polymerase chain reaction conditions and visualization of PCR product were as described previously.

To develop the multiplex PCR assay, the reverse primers for the parasitoids (Table 1) were mixed with universal forward primer LCO in a single reaction tube, and then parasitoid DNA from eight individuals of each of the three species was challenged with the combined primers. Polymerase chain reaction conditions and visualization of the PCR product were as described previously, except that the annealing temperature used in the multiplex assay was 54°C. Extracts of DNA from healthy, unparasitized *E. fimbriata* were included in the assay to check for cross-reactivity.

Validation of the multiplex PCR assay

In 2011, *E. fimbriata* (green and red morphs, alatae and aperterae, immatures except first instars) were collected weekly during May through early September from a 0.15-ha research trial of 6-year-old highbush blueberry 'Duke' plants at the Pacific Agri-Food Research Centre in Agassiz, B.C. (study site reported by Ehret *et al.* 2012). Mature and immature aphids were collected by detaching the leaves on which they were feeding. All aphids were later transferred with a fine paintbrush to the blueberry terminals in buckets described below. The aphid population varied according to trends described by Raworth (2004), therefore the number of aphids collected each week ranged from 65 to 500. About half of the weekly total number of collected aphids were reared to allow parasitoids to develop and emerge (except for the first week, when all collected aphids were reared). The numbers of aphids in rearing were 62, 173, 50, 146, 174, 160, 174, 155, 250, 220, 225, 225, 232, 215, 225, 259, 157, 95 and 51, respectively, for each of the 19 weeks. In the rearing assay, aphids were placed on blueberry terminals cut from plants in the field then washed to ensure they were insect-free. The blueberry terminals stood in a small volume of water in 1.9-litre buckets with mesh lids under natural light at 21 ± 2°C for 30 d. Each week, aphids to be reared were placed in one bucket. The age structure of the sample of aphids was not estimated. Parasitoids that emerged from the group of reared aphids were identified to species (as per Pike *et al.* 2011) and preserved in 70% ethanol. Voucher specimens are stored by K. Pike. Aphids not used in the rearing assay were preserved in 95% ethanol. A subset of these preserved aphids was used for DNA analysis. The multiplex PCR assay was validated by comparing the percentage of aphids that hosted primary parasitoids in the rearing assay with the percentage of preserved aphids that revealed parasitoid DNA. Statistical support for this comparison was generated by calculating the chi-square statistic (Yates' corrected where appropriate; SYSTAT 2007) on the numbers of primary parasitoids that emerged from groups of reared aphids versus the numbers of preserved aphids in which parasitoid DNA was detected by PCR.

RESULTS AND DISCUSSION

Development of specific primers for singleplex and multiplex PCR assays

The extracted mitochondrial DNA from all parasitoid specimens amplified successfully with the universal primers and produced distinct bands on agarose gel. The COI sequences (649 bp) showed high A–T content with an average of 74% of either A or T. The consensus COI sequences for *A. ericaphidis*, *E. incompletus*, and *P. unicum* (and for *A. ervi* Haliday, *A. matricariae* Haliday, *P. gallicum* Starý, *P. humulaphidis* Ashmead, and *P. occidentale* Baker from an unpublished study by Mathur *et al.*) were deposited in the National Center for Biotechnology Information GenBank under accession numbers EU574902-EU574906, GU237129-GU237131 and KC211020-211032.

All sequences in the sample population of 33 *A. ericaphidis* were identical; therefore, there was only one haplotype (KC211024) and no intraspecific divergence. Within the sample

Figure 1. Specificity of multiplex PCR assay. Specific reverse primers for *A. ericaphidis*, *E. incompletus* and *P. unicum* were combined and tested with DNA from: *P. unicum*, Lanes 1–3; *E. incompletus*, Lanes 4–6; *A. ericaphidis*, Lanes 7–9. Lane 10 is a water control and Lanes M are 100-bp markers.

population of 13 *E. incompletus*, the average intraspecific divergence was 1.31% (range 0.3–2.4%), and seven haplotypes were identified: haplotype 1 (KC211027) was represented by six sequences, haplotype 2 (GU237131) was represented by two sequences, and haplotypes 3 (KC211028), 4 (KC211029), 5 (KC211030), 6 (KC 211031), and 7 (KC211032) were represented by one sequence each. Within the sample population of 37 *P. unicum*, the average intraspecific divergence was 0.42% (range 0.2–0.6%), and five haplotypes were identified: haplotype 1 (KC211020) was represented by 31 sequences, and haplotypes 2 (KC211021), 3 (KC211022), 4 (KC211023), and 5 (EU574904) were represented by 1, 1, 2, and 2 sequences, respectively.

The specific reverse primers designed for *A. ericaphidis*, *E. incompletus* and *P. unicum* (Table 1), when used individually with forward universal primer LCO, selectively amplified the DNA of the species for which they were designed. In the multiplex PCR assay, the combination of universal forward primer and all three specific reverse primers differentiated adults of *A. ericaphidis*, *E. incompletus* and *P. unicum*, and amplified the appropriate specific fragments: 130 bp for *A. ericaphidis*, 261 bp for *E. incompletus* and 404 bp for *P. unicum* (Fig. 1).

Validation of the multiplex PCR assay

Only three species of braconid primary parasitoids emerged from *E. fimbriata* collected from the Agassiz site (Fig. 2). Although other species of *Aphidius* and *Praon* have previously been reared from field-collected aphids in southwestern B.C. (Raworth *et al.* 2008), no additional species of these two genera were recovered in our study. As such, the primers we have developed can be used to identify the species of primary parasitoids from this site. *Praon unicum* emerged from the earliest collections of *E. fimbriata* in May, and was present in hosts throughout the collection period. *Aphidius ericaphidis* first emerged from hosts collected in late June, and was present throughout the rest of the collection period. A very small number of *E. incompletus* emerged from hosts collected in July, August and early September. A total of 10 hymenopteran parasitoid individuals (not shown in Fig. 2) that could not be identified by morphological characteristics emerged from aphids collected in May, June and early July. Secondary (hyper-) parasitoids (*Alloxysta* sp., as noted by Raworth *et al.* 2008) first emerged in late June, and were present every week (1–20 per week) until early September.

Peak numbers of one or both of the two dominant species, *A. ericaphidis* and *P. unicum*, emerged from hosts collected on 28 June, 20 July, 10 and 23 August, and 1 and 9 September (Fig. 2). To validate the multiplex PCR assay, DNA from 24–40 preserved *E. fimbriata* collected on each of 28 June, 20 July, 10 August and 1 September was challenged with the combined specific reverse primers (e.g., Fig. 3). On all four dates, multiplex PCR detection of percentage parasitism by either *A. ericaphidis* or *P.*

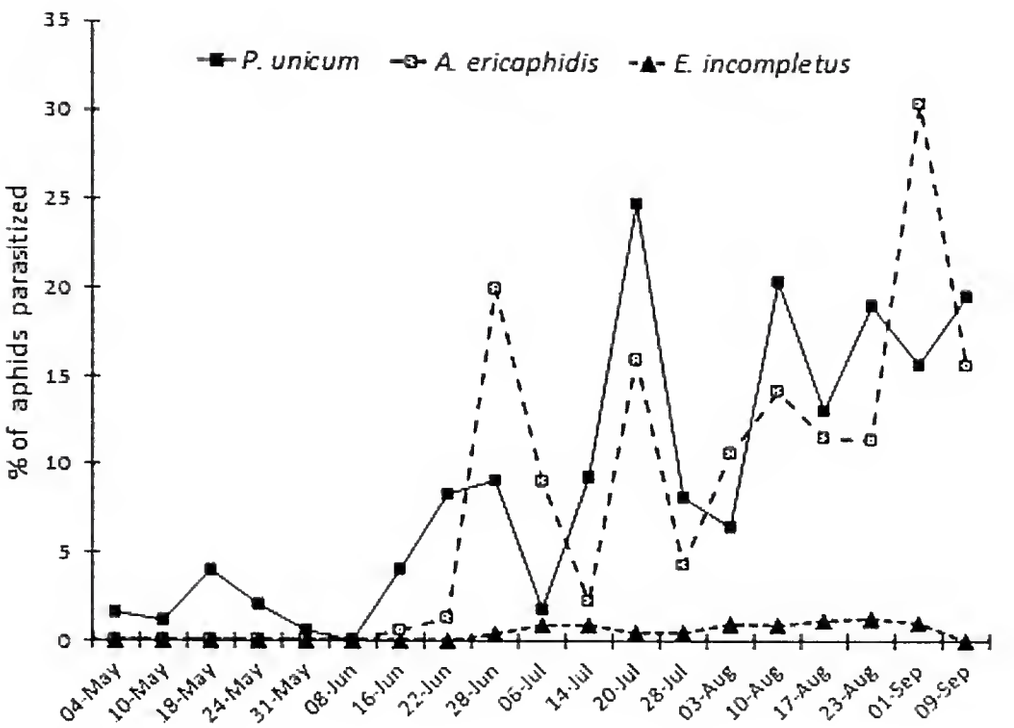

Figure 2. Percentage of field-collected *E. fimbriata* from which parasitoids emerged. Numbers of field-collected *E. fimbriata* reared from highbush blueberry were 62, 173, 50, 146, 174, 160, 174, 155, 250, 220, 225, 225, 232, 215, 225, 259, 157, 95 and 51, respectively, for each of the 19 weeks in 2011.

unicum was statistically similar to detection of parasitism by rearing field-collected *E. fimbriata* ($P>0.05$ in 8 individual comparisons; Table 2). The numbers of *E. incompletus* were too small for valid chi-square analysis (Fig. 2, Table 2). The multiplex PCR assay detected *E. incompletus* DNA on two of the four dates, whereas *E. incompletus* individuals were reared from aphids collected on each of the four dates. It is possible that primers in the multiplex assay did not detect some of the earliest, tiniest life stages (e.g., eggs) of *E. incompletus* or of the other two parasitoids. To establish detection limits of the primers, a third method of detection—dissection—should be compared with the multiplex PCR assay and the rearing methods (as per methods described by Gariepy *et al.* 2007 and Weathersbee *et al.* 2004). Additionally, sensitivity analysis of the multiplex PCR assay might help to explain some of the differences between the two detection techniques in our study.

The multiplex PCR assay detected DNA from both *A. ericaphidis* and *P. unicum* in a small percentage of *E. fimbriata* collected on 20 July, 10 August and 1 September (Table 2; Fig. 3, Lane 6), indicating multiparasitism by these two species. Stage-specific information about this competitive interaction between primary parasitoids could be obtained by dissecting the immature stages out of aphid hosts and challenging their DNA with the multiplex assay. More dynamic information about the outcomes of multiparasitism in field-collected *E. fimbriata* could be gathered by comparing a single-aphid rearing assay with dissection followed by the multiplex PCR assay. Rearing assays of multiparasitism by *A. smithi* and *P. pequodorum* on pea aphid, *Acyrthosiphon pisum*, showed that the survivor of competition between a first-instar *P. pequodorum* and any stage of *A. smithi* was *P. pequodorum*; but if *P. pequodorum* was killed in the egg stage, *A. smithi* survived (Chow and Mackauer 1984, 1985).

The trend toward increased multiparasitism between 20 July and 10 August suggests that fewer hosts were available because the *E. fimbriata* population was in decline due to seasonal changes in host-plant quality (Raworth 2004; Raworth and Schade 2006) and might indicate that parasitoid populations were increasing at that time.

Conclusions

The molecular diagnostics developed in this study can be used, in conjunction with rearing and dissection techniques, to conduct

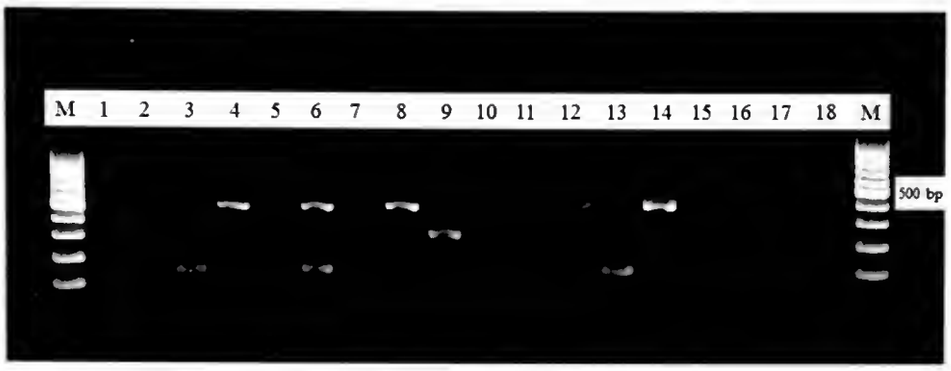

Figure 3. Use of the multiplex PCR assay to detect parasitoid DNA in *E. fimbriata* collected on 20 July 2011 from highbush blueberry. Of 24 *E. fimbriata* analysed, 17 are represented in this figure. Results from one aphid are shown in each of Lanes 1–17. Lanes 1, 2, 5, 10, 11, 15, 16 and 17 show no parasitism (Lane 17 shows as a negative control: one *E. fimbriata* that was known to be unparasitized). Lanes 3, 7 and 13 show parasitism by *A. ericaphidis* (130 bp); Lane 9 shows parasitism by *E. incompletus* (261bp); Lanes 4, 8, 12 and 14 show parasitism by *P. unicum* (404 bp); and Lane 6 shows multiparasitism by *A. ericaphidis* and *P. unicum*. Lane 18 is a water control and Lanes M are markers. At the bottom of most lanes is a faint band (80 bp) from leftover PCR ingredients.

detailed studies of the population dynamics of the primary parasitoids of *E. fimbriata* in southwestern B.C., with or without the augmentative releases of *P. unicum* proposed by Raworth *et al.* (2008; and see Vafaie *et al.* 2013). In particular, it will be possible to track the immature stages of *A. ericaphidis*, *E. incompletus* and *P. unicum* in a single reaction using the multiplex PCR assay.

The diagnostic accuracy of the multiplex PCR could likely be improved by: sensitivity analysis of the PCR; analyses to determine if DNA from one species inhibits the PCR reaction to DNA of other species; and analysis of DNA from parasitoids congeneric to *A. ericaphidis*, *E. incompletus* and *P. unicum*.

Once these improvements have been made, the multiplex PCR would be useful on a larger geographical scale. *Aphidius ericaphidis* has been discovered in large numbers east and west of the Cascades, USA, as well as in southwestern B.C. (Raworth *et al.* 2008; Pike *et al.* 2011). *Praon unicum* has been reported from more than 30 different aphid hosts (see Smith 1944; Carroll and Hoyt 1986; Johnson 1987; Pike *et al.* 1997, 2000; Acheampong *et al.* 2012) besides *E. fimbriata*. The primers developed for *P. unicum* will, therefore, facilitate population studies in other systems.

Table 2

Number (%) of *E. fimbriata* from which a parasitoid emerged during rearing (R) compared to number (%) of *E. fimbriata* in which parasitoid DNA was detected by multiplex PCR assay (M).

Date (2011) of *E. fimbriata* collection	Species of parasitoid detected							
	P. unicum		*A. ericaphidis*		*E. incompletus*		*A.e.* plus *P.u.*[a]	
	R	M	R	M	R	M	R[b]	M
28 June	9.1	5.0	20.0	15.0	0.4	0	-	0
20 July	24.8	25.0	16.0	20.8	0.4	4.2	-	4.2
10 August	20.4	29.2	14.2	25.0	0.9	0	-	8.3
1 September	15.7	33.3	30.5	41.7	1.0	4.2	-	8.3

a Multiparasitism by *A. ericaphidis* and *P. unicum*.

b *Ericaphis fimbriata* was reared in groups, therefore the number of parasitoids emerging from one aphid could not be determined.

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Seasonal Flight Pattern of the Western Balsam Bark Beetle, *Dryocoetes confusus* Swaine (Coleoptera: Curculionidae), in Central British Columbia

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ABSTRACT

Seasonal flight pattern of the western balsam bark beetle, *Dryocoetes confusus* Swaine, in stands of subalpine fir, *Abies lasiocarpa* (Hook) Nutt., in north–central British Columbia was monitored for three years using multiple-funnel traps baited with (±)-*exo*-brevicomin. Two major flight periods occurred per year, the first commencing in mid- to late June, and the second occurring in mid- to late August. The first flight was predominantly males, while the second flight was composed primarily of females, probably re-emerged parent adults. Little flight occurred until within-stand temperatures exceeded 15°C. Traps placed 6 m above the ground caught four times as many beetles as traps placed 2 m above the ground. Our results indicate that semiochemical-based manipulation of the western balsam bark beetle should be implemented by early May.

Key Words: Coleoptera: Curculionidae, Scolytinae

INTRODUCTION

The western balsam bark beetle, *Dryocoetes confusus* Swaine, occurs throughout the range of its host, subalpine fir, *Abies lasiocarpa* (Hook) Nutt., from British Columbia to New Mexico (Bright 1963). The beetle is the most destructive insect pest of mature and overmature subalpine fir in British Columbia (Garbutt 1992).

Mathers (1931) described a two-year life cycle for *D. confusus* in central B.C. First emergence of new adults occurs in late June, and continues throughout July. These adults attack fresh host material, with the attacking males excavating nuptial chambers. Male *D. confusus* are polygamous, and mate with up to four females (Bright 1976). Females excavate brood tunnels and lay eggs until "well into August" (Mathers 1931). After egg laying is completed, the parent adults extend brood tunnels by feeding, creating tunnels in which they overwinter. The following spring, females lay a second brood in a continuation of these same tunnels. Parent adults then re-emerge in mid-July to attack fresh material, and lay a third brood. Eggs of the first brood hatch in late August, overwinter as small larvae, develop to teneral adults, and overwinter again. Progeny of the second brood, beginning early the second summer, develop in a similar way. The third brood, beginning late in the second summer, begins to hatch by the third week in August (Mathers 1931). Thus, Mathers (1931) identified two clearly defined flight periods, of which the second had re-emerging adults.

Baited multiple-funnel traps have been used to monitor *D. confusus* flight periods for three years in Utah, USA (Hansen 1996), and for three years in northern Idaho and western Montana, USA (Gibson *et al.* 1997). Both studies identified two flight peaks, with the main part of the first peak occurring from mid-June to early July, and the second variably in August to September. In Utah, the relative size of the two flight peaks varied across elevations, with a trend towards larger first peaks at higher elevations, and larger second peaks at lower elevations. Both studies

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noted a larger percentage of male beetles in the early-season flight, and a trend towards more females in the later season flight.

Hansen (1996) noted that very little flight occurred when ambient temperatures were less than 15°C, although low temperatures were not a factor separating the two seasonal flight peaks.

Our objectives were to describe the seasonal flight patterns of *D. confusus* and to assess the vertical distribution of within-stand flight in central British Columbia.

MATERIALS AND METHODS

Eight-unit multiple-funnel traps (Lindgren 1983) were set in the Bulkley Valley, central British Columbia, in the Engelmann Spruce–Subalpine Fir or Sub-Boreal Spruce biogeoclimatic zones (Banner *et al.* 1993), annually in 1985, 1986, and 1987. Trapping periods and locations for monitoring seasonal flight were 19 June–22 August 1985 (10 traps) at McKendrick Pass, 13 June–27 August 1986 (6 traps), at Gramophone Creek, and 28 May–27 August 1987 (10 traps) at Kwun Creek. Traps were suspended on ropes between two trees in stands with active beetle infestations, and were placed at least 50 m apart. The top of each trap was hung approximately 2 m above ground in 1985 and 1986. Based on results from 1986 of vertical distribution of within-stand flights, the top of each trap was raised to 3 m in 1987. Attractive baits used in each trap were the aggregation pheromone (±)-*exo*-brevicomin (Albany International, Columbus, Ohio) 99.7% purity (Borden *et al.* 1987), in two glass capillary tubes, collectively releasing 0.4 mg/24 h in 1985 and 1986. Based on results from experiments in 1986 (Stock *et al.* 1995), the release rate of trap baits was increased to four capillary tubes, collectively releasing 0.8 mg/24 h ((±)-*exo*-brevicomin, 98.0% purity, Contech Inc., Delta, B.C.) in 1987. Captured *D. confusus* were counted and sexed daily in 1985, and on Mondays, Wednesdays, and Fridays in 1986 and 1987. Within-stand temperature and relative humidity patterns were monitored with a hygrothermograph (C.F. Casella and Co., London, UK, Model 3083/TT) placed in a Stevens box located under the canopy on the ground near the funnel traps.

In a separate experiment in 1986, 10 *exo*-brevicomin–baited 8-unit multiple-funnel traps spaced 50 m apart were set out at Gramophone Creek. Five traps were selected randomly to be suspended approximately 2 m above ground, and five to be suspended approximately 6 m above ground. The experiment was established on 19 June, and ended on 11 July.

Data from the trap height experiment were compared using a t-test (Number Cruncher Statistical System 1988).

RESULTS

Seasonal flight patterns (Fig. 1) indicated that *D. confusus* has at least two flight periods each summer. The first (main) flight period occurred in mid- to late June, and the second in mid-August. Flight had probably started prior to trap placement in 1985 and 1986, as evidenced by catches in the first collection period. Peaks in flight activity generally occurred when maximum daily ambient temperature was 15°C or warmer (Fig. 1). Relatively little flight occurred in the interval between flight peaks, despite apparently adequate maximum temperatures. The trends for cumulative captures were roughly similar each year, showing a slow rise followed by a sharp increase, with the pattern then repeating itself (Fig. 2). By assuming a separation of the two flights on 1 August, the second flight represented 19% of total flight in 1985, 17% of total flight in 1986, and 26% of total flight in 1987. Small numbers of beetles flew in September in all years after the traps had been taken down (pers. observations).

Cumulatively, for the three years of study, less than 5% of total trap catch occurred when daily maximum temperatures within stands were less than 15°C.

The overall proportion of captured males was 0.46 in 1985, 0.67 in 1986, and 0.44 in 1987 (Fig. 3). However, males predominated early in the season, and the sex ratio became progressively female-biased over time. The

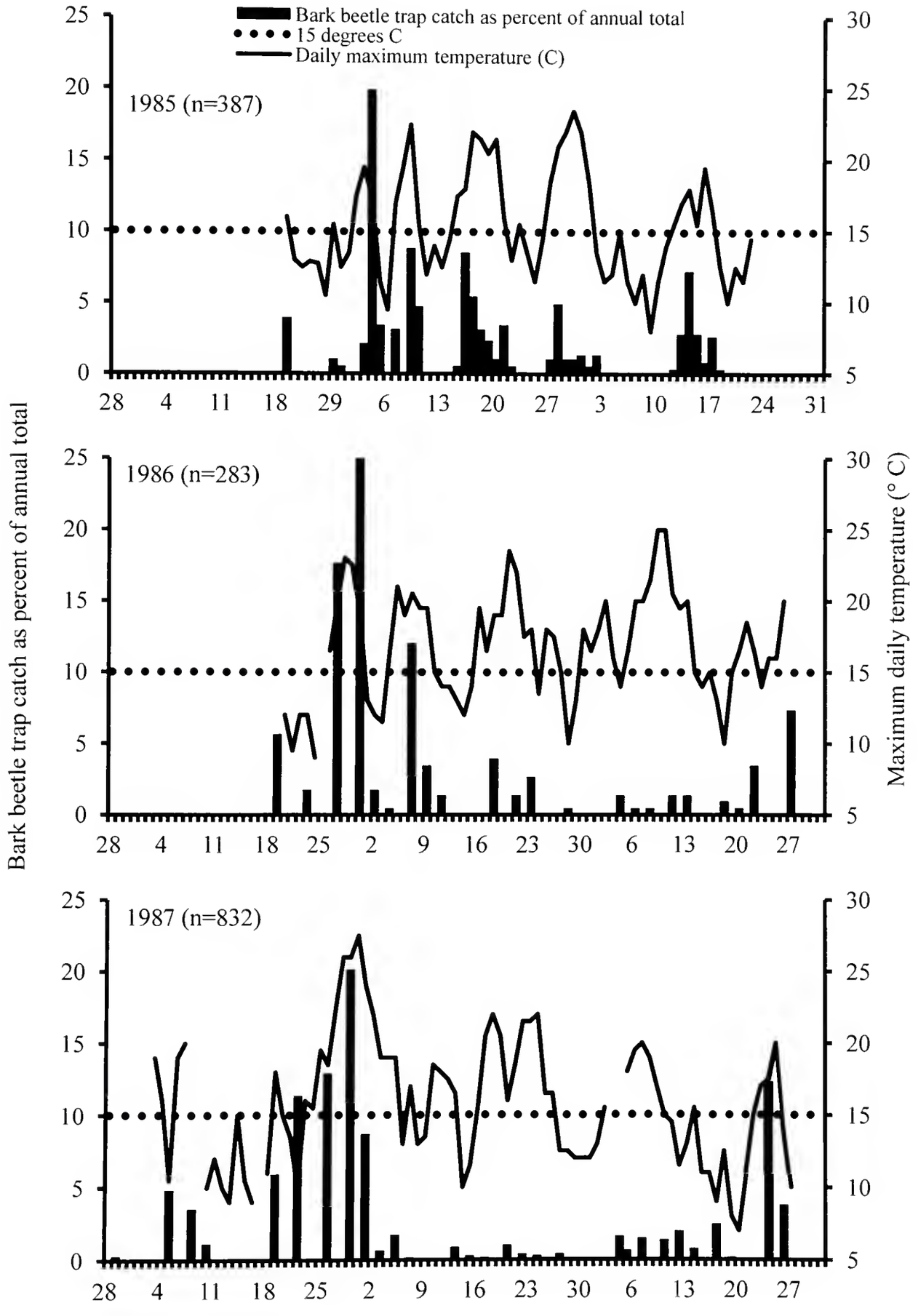

Figure 1. Seasonal flight patterns and maximum daily temperatures for *Dryocoetes confusus* caught in *exo*-brevicomin–baited multiple funnel traps at Gramophone Creek, B.C., 1985–1986, and Kwun Creek, B.C., 1987.

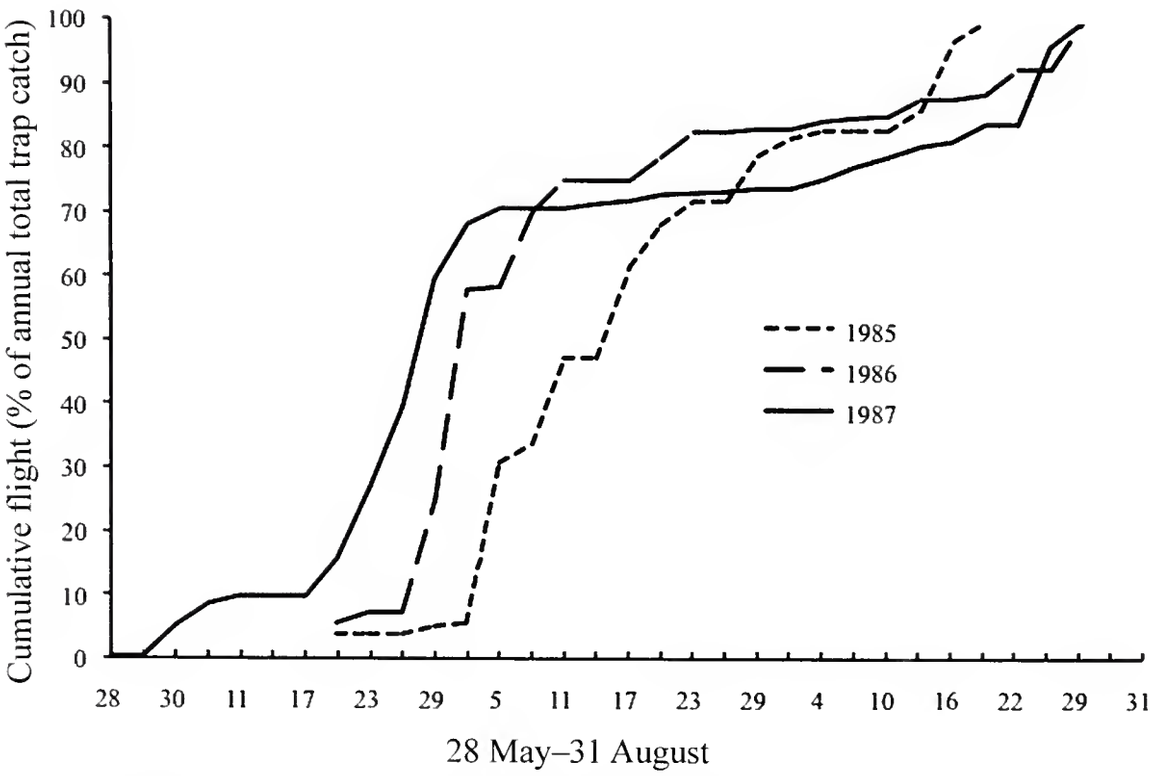

Figure 2. Cumulative trap catch as percent of annual total trap catch for *Dryocoetes confusus* caught in *exo*-brevicomin–baited multiple funnel traps at Gramophone Creek, B.C., 1985–1986, and Kwun Creek, B.C., 1987.

less well-defined trend in 1986 could be due to the generally cooler weather early in the summer, which may have affected the emergence of one of the sexes. Also, there were relatively few beetles caught in 1986 (Fig. 1), which may have increased variation, resulting in weaker trends (see also Fig. 2).

Approximately four times more beetles were captured in traps at the 6 m height than at 2 m (Table 1).

DISCUSSION

The evidence that the main flight period of the western balsam bark beetle occurs primarily in mid- to late June corresponds well with Mathers' (1931) data on life history. Some caution may be needed when interpreting results of pheromone-baited funnel traps for monitoring scolytid flight periods (Bentz 2006). Pheromone-baited traps within stands may catch disproportionately more beetles during periods of reduced beetle flight, and disproportionately fewer beetles during peak beetle flight, producing an "elongated" flight period that may not coincide well with actual beetle emergence from trees (Bentz 2006). However, for semiochemical-based management, it is necessary to know when beetle flight actually commences in stands, and we are confident our results indicate that *D. confusus* flight can begin in early June or late May (Fig. 1), when ambient temperatures are higher than 15°C. This temperature threshold is consistent with Hansen (1996) and Negrón and Popp (2009). Hansen (1996) noted that snow was mostly gone before flight commenced. The occurrence of the second peak in mid-August in central BC, however, was one month later than the mid-July re-emergence described by Mathers (1931). This may have been due to weather. Temperature-driven variation in development is common in other scolytid species: it can shorten their life cycles when warm weather permits, or lengthen them to endure periods of cold (Amman 1973; Schmid and Frye 1977; Langor 1987; Wermelinger and Seifert 1999). Flight peaks of the western balsam bark beetle appear to be variable across the landscape and highly weather dependent (Hansen 1996; Gibson *et al.* 1997; Negrón and Popp 2009). This information should prompt further investigations to discover if *D. confusus* can indeed develop on

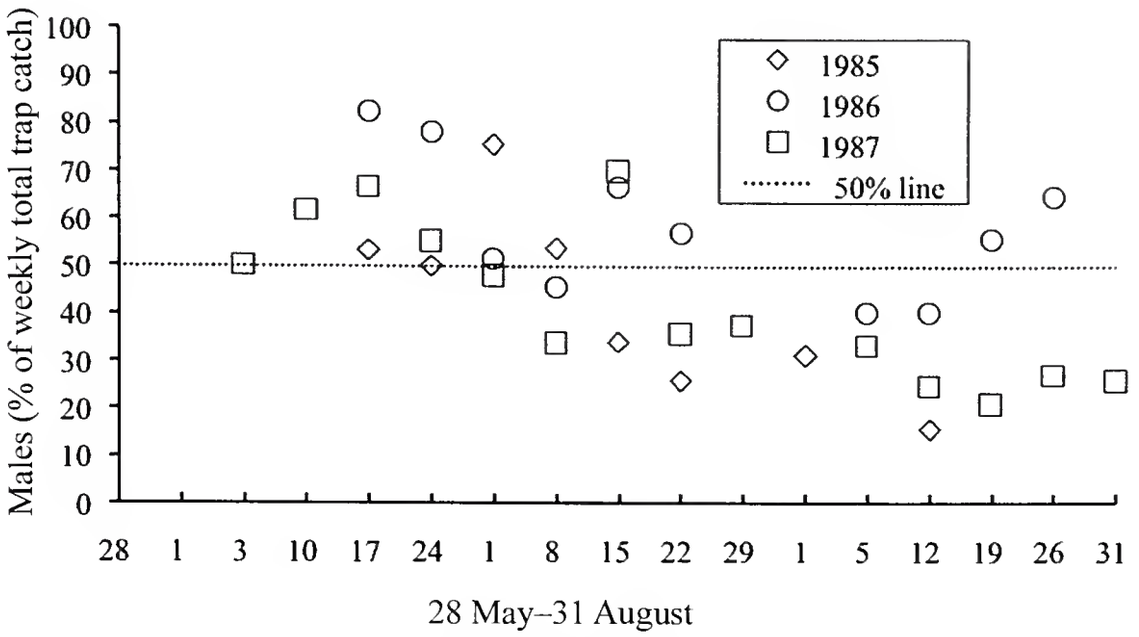

Figure 3. Seasonal variation in the male component of flying *Dryocoetes confusus* populations, Gramophone Creek, B.C., 1985–1986, and Kwun Creek, B.C., 1987.

a one-year cycle, as suggested by Bright (1963), and which does occur in *Dryocoetes autographus* (Johansson *et al.* 1994) and the spruce beetle, *Dendroctonus rufipennis* (Schmid and Frye 1977). Such a life cycle may become more prevalent under conditions of global warming. Further work is also necessary to assess efficacy of baited funnel traps for monitoring beetle flight, as per Bentz (2006). It is essential to understand variability in life-cycle duration and flight periods in order to implement pest management tactics, e.g., semiochemical-based population manipulation, effectively.

The period between flight peaks corresponds to when females in galleries are laying a second brood (Mathers 1931) and/or feeding to regenerate their flight muscles (Chapman 1957; Borden and Slater 1969; Bhakthan *et al.* 1970; Bhakthan *et al.* 1971). Exact information on when first-, second-, or third- brood beetles are represented in flying populations at higher latitudes awaits further study.

The overall proportions of captured males conformed well to the 0.43 proportion of males in emerging beetle broods (Stock 1981). There was no evidence for an early emergence of the responding sex (females; Fig. 3), considered to be an outbreeding mechanism in other scolytids (Cameron and Borden 1967; Billings and Gara 1975; Borden 1982). Rather, there is evidence for early emergence of the pioneering sex (males; Fig. 3), which is consistent with Hansen (1996) and Negrón and Popp (2009). Early emergence of the pioneering sex has been shown for summer brood *Ips typographus* L. (Botterweg 1983) and *I. perturbatus* (Graves 2008). It is possible that in uneven-aged multi-storied old-growth subalpine forests, the patchy and temporary nature of the host resource (newly susceptible or freshly downed trees; Bleiker *et al.* 2003, 2005) may force beetle populations to search over large areas. Early emerging males could establish new attraction centres, resulting in multiple matings with local females and enhanced population genetic heterogeneity (Flamm *et al.* 1987). If the responding sex were to emerge first in such a harsh environment, the uncertainty of initial attack success, establishment of secondary attraction, and ultimately mass-aggregation (Borden *et al.* 1986) could be increased, resulting in high mortality of the responding sex during dispersal. Subsequent re-emergence of females late in the summer may further enhance genetic heterogeneity (Cameron and Borden 1967).

We hypothesize that a significant proportion of the second flight is comprised of re-emerging adults. Flamm *et al.* (1987) found that 75% and 64% of attacking *Ips avulsus* Eichoff and *I. calligraphus* Germar, respectively, re-emerged from original host trees, and that males represented only 27.8% of reemerging *I. avulsus*, compared to 46.7% of re-emerging *I. calligraphus*. Anderbrandt *et*

Table 1
Catch of *D. confusus* in a five-replicate experiment with 8-unit (±)-*exo*-brevicomin–baited funnel traps set at 2 and 6 m above ground, 19 June–11 July 1986, Gramophone Creek, B.C.

	Total number of beetles per trap (Mean ± S.E.)a	
Trap height	Males	Females
2m	15 ± 3.0a	5 ± 1.8a
6m	49 ± 9.8b	29 ± 7.2b

a Means within columns followed by the same number are not significantly different, t-test, $p \leq 0.0250$.

al. (1985) found that about 84% of *I. typographus* reemerged, of which about 36% were males. It is possible that those females fit enough to re-emerge gain an adaptive advantage by exploiting unused bark in previously attacked, but not fully utilized trees (Flamm *et al.* 1987). A portion of the second flight peak may also be generated by broods originating in downed materials (Negrón and Popp 2009), if development were delayed because of snow cover.

Our results indicate that pest management tactics such as semiochemical-based management (Stock *et al.* 1990, 1993, and 1995; Maclauchlan *et al.* 2003; Jeans-Williams and Borden 2006) need to be implemented by early May. Finer-scale silvicultural approaches such as group selection or small patch harvesting (Veblen *et al.* 1991; Stock *et al.* 1993; Maclauchlan *et al.* 2003) would need to account for the period when re-emerged, and presumably gravid, females are active; e.g., delay implementation until September.

The tendency of *D. confusus* to fly well above ground within stands has been shown for other scolytid species. Beetles with such flight patterns presumably avoid the impediments of understorey vegetation and dense tree crowns, and are positioned to intercept pheromone plumes (Ashraf and Berryman 1969; Schmitz *et al.* 1980; Amman and Cole 1983; Bartos and Amman 1989). Understorey vegetation can be 3 or 4 m high in subalpine forests. Waters and Stock (1995) counted attack densities at 1.3, 4 and 8 m height, and found that beetle attacks per square metre were greatest at 4 m above ground, although the difference between heights was not significant. Flight height may not be correlated to attack success, although Maclauchlan *et al.* (2003) hypothesize that cool nighttime temperatures near the ground or wetness and non-vectored fungal development under the bark may limit gallery success in the lower two metres of the bole.

It would be useful to know, for semiochemical-based manipulation of *D. confusus* populations, what relationship this flight pattern might have to the initial attack height and vertical distribution of attack density by *D. confusus* on standing trees.

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SCIENTIFIC NOTE

Update on the establishment of birch leafminer parasitoids in western Canada

Chris J.K. MacQuarrie[1], Daryl J. Williams[2], and David W. Langor[2]

Five species of birch (*Betula*) leaf-mining sawfly have been introduced to Canada. The two most damaging species, *Profenusa thomsoni* (Konow) and *Fenusa pumila* Leach (previously known as *F. pusilla*), have wide distributions in western Canada (Digweed *et al.* 2009) and can be significant pests of birch in the region. The larvae of both species feed inside the leaf and cause brown blotch-shaped mines that are characteristic for each species. When outbreaks of these species occur, the large numbers of larvae create multiple mines within individual leaves. This damage causes trees to take on a burnt appearance, which is often considered undesirable in urban settings where birch is a popular ornamental tree. Over the last 20 years, we have studied the distribution and impact of these birch leaf-mining sawflies and their biological control using parasitoids in the Ichneumonid genus *Lathrolestes* Foerster (Digweed *et al.* 2009, MacQuarrie *et al.* 2013).

In Canada, outbreaks of *F. pumila* and *P. thomsoni* have been controlled by the introduction and redistribution of two species of *Lathrolestes* that attack the larvae as they feed within the leaf (Quednau 1984, Langor *et al.* 2002, Digweed *et al.* 2003, MacQuarrie *et al.*, 2013). Outbreaks of both sawfly species have been noted in western Canada, but since the 1990s *P. thomsoni* has been responsible for most of the observed damage. The sawfly is controlled by *Lathrolestes thomsoni* Reshchikov (previously known as *L. luteolator*), an endoparasitoid that was first observed attacking *P. thomsoni* during the late 1990s in Edmonton, Alberta (Digweed *et al.* 2003). In the early 2000s, other populations of the parasitoid were found attacking the sawfly in Hay River and Fort Smith, Northwest Territories, as well as in Edson, Alberta (MacQuarrie 2008). These parasitoid populations were later exploited for a biological control project against an outbreak of *P. thomsoni* in Alaska. This project successfully established *L. thomsoni* in at least one site in the state (MacQuarrie 2008, Soper 2012), and demonstrated that relocating free-living adult *L. thomsoni* is a feasible way to establish the parasitoid within an outbreak population of *P. thomsoni*.

In the early 2000s, outbreaks of *P. thomsoni* were reported in the Northwest Territories and northern British Columbia. To help suppress these populations, we collected adult *L. thomsoni* from Edson, Edmonton, Hay River and Fort Smith, and released them in Prince George, British Columbia, and Yellowknife, Northwest Territories (MacQuarrie 2008). We surveyed these populations in 2012 to determine: 1) if *L. thomsoni* had established; and, 2) how abundant it was. A survey in 2003 found that *P. thomsoni* was also present throughout much of the southern Yukon but not at outbreak levels (Digweed and Langor 2004). Therefore, we also surveyed in the Yukon to determine if *P. thomsoni* had changed in abundance and if *L. thomsoni* was present.

In the summer of 2012, we surveyed for *L. thomsoni* in Prince George, Yellowknife and Whitehorse, Yukon, using traps (7.5 cm x 12.5 cm yellow sticky cards; Contech Inc., Victoria, BC) set out at two or three sites in each city. In both Prince George and Yellowknife, one site was situated near the original release site and another site was established elsewhere. The two Prince George sites were located in a wooded area and in the yard of a private home, and were approximately 1.1 km apart. The two Yellowknife sites were both located in the

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yards of private homes and were approximately 2.5 km apart. In Whitehorse, the sites were located in wooded areas near a major road (two sites) and along a walking trail (one site). These sites were approximately 0.5–3.0 km apart.

At each site, three birch trees were selected by local volunteers, and a trap was hung at head height (approx. 2 m) in each tree. Traps were placed in early or mid-June, depending on the advancement of the season, and replaced weekly until early or mid-July, depending on the duration of *P. thomsoni* adult flight (Table 1). This study was intended for detection and not for population assessment. Volunteers were therefore allowed to carry out surveys according to their own local conditions rather than according to a prescribed method. This meant the number of traps hung in each city and at each site varied depending on how frequently the traps were changed. We report the total number of traps hung at each site over the trapping period (Table 1). The volunteers returned the traps at the end of the season, at which time we examined the traps' contents. Identification of all material on the traps was done by one of the authors (D. J. Williams).

We found *L. thomsoni* to be established in Prince George, and established and abundant in Yellowknife (Table 1). Populations of the sawfly at both release sites appear to be large relative to the size of the parasitoid populations. Parasitism rates (percent of the total catch that was adult parasitoids) ranged from 11–17% in Yellowknife and 6–8% in Prince George. In contrast, the *P. thomsoni* population in Whitehorse appeared to be small, and a parasitoid population was not detected (Table 1).

Our survey indicates *L. thomsoni* has established in Prince George and Yellowknife. Suppression of either population was not tested, but anecdotal evidence suggests that damage by *P. thomsoni* has been less evident in recent years (MacQuarrie *et al.* 2013). However, even when populations are large, the appearance of damage caused by *P. thomsoni* can vary from year to year (MacQuarrie 2008), and a decrease in visible damage may not indicate a sawfly population

Table 1

Summary of trap catches for adult *Profenusa thomsoni* (Konow) and adult *Lathrolestes thomsoni* Reshchikov for three cities in 2012.

				P. thomsoni		*L. thomsoni*	
Trapping period	Days	Site	Total traps	Percent positive traps (n)	Total adults	Percent positive traps (n)	Total adults
Prince George, British Columbia							
21 June– 4 July	13	1	20	60% (12)	82	15% (3)	7
		2	20	75% (15)	63	20% (4)	4
Whitehorse, Yukon							
8 June– 17 July	39	1	15	13% (2)	3	0% (0)	0
		2	15	0% (0)	0	0% (0)	0
		3	15	13% (2)	3	0% (0)	0
Yellowknife, Northwest Territories							
4 June– 16 July	42	1	14	71% (10)	1931	57% (8)	236
		2	24	54% (13)	862	38% (9)	177

experiencing suppression by the parasitoid. Repeated observations of both populations, including an assessment of parasitism rates, would be necessary to confirm if *L. thomsoni* is controlling *P. thomsoni*.

The population of *P. thomsoni* in Whitehorse is small, and *L. thomsoni* does not appear to be present. We suggest that Whitehorse be monitored at regular intervals to assess the status of the *P. thomsoni* population. Should an outbreak occur, the established *L. thomsoni* populations in Yellowknife and Prince George could serve as sources of parasitoids for release in Whitehorse.

Determining the true impact of *L. thomsoni* on the dynamics of the Prince George and Yellowknife *P. thomsoni* populations requires collecting and rearing large numbers of leafminers to obtain an estimate of the percent parasitism. Such estimates have been done for other *P. thomsoni* populations, but the work requires significant time, effort, and financial resources to make an accurate assessment (MacQuarrie 2008). These resources are hard to obtain for species, like *P. thomsoni*, that are considered minor, aesthetic pests. In contrast, sampling adult parasitoids, while a less precise estimate than rearing, is a simple and inexpensive way to determine the presence and relative abundance of a parasitoid.

We are optimistic that control of the sawfly will be achieved at Prince George and Yellowknife, based on the observation that *L. thomsoni* has persisted at both sites for at least five years without any assistance or augmentation. This suggests that the *L. thomsoni* populations at these sites are resilient and should be able to maintain their presence into the future.

ACKNOWLEDGEMENTS

We thank S. Lindgren, University of Northern British Columbia, Prince George; S. Carriere and D. Taylor, Government of the Northwest Territories, Yellowknife; and B. Godin, Environment Canada, Whitehorse, for their assistance in placing and monitoring sticky traps; and R. Johns and three anonymous reviewers for their comments on an earlier version of this manuscript.

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SCIENTIFIC NOTE

British Columbia's 50th mosquito species, *Aedes schizopinax*

M. Jackson[1], C. Pyles[1], S. Breton[1], T. J. S. McMahon[1] and P. Belton[2]

Larvae of *Aedes* (*Ochlerotatus*) *schizopinax* Dyar, 1929 (Diptera: Culicidae) were collected in a survey by Culex Environmental for the District of Sparwood by Sylvia Breton on 12 May 2013. The site (Fig. 1) was a roadside pool near Sparwood, British Columbia (B.C.), approximately 20 km west of the Alberta border. Vegetation around the pool was mostly pine grass (*Calamagrostis rubescens* Buckley) with wild rose (*Rosa acicularis* Lindl.) in front of willow (*Salix* sp.), cottonwood (*Populus* sp.) and lodgepole pine (*Pinus contorta* Douglas). Representative specimens will be deposited in the Beaty Biodiversity Museum, University of British Columbia. In the 30 years since the publication of the Provincial Museum handbook on the mosquitoes of British Columbia (Belton 1983), four additional species have been collected in the province. They all have been examined by Dr. Peter Belton. The identities of two of these species, *Culex boharti* Brookman and Reeves and *Culex restuans* Theobald, are being confirmed. *Culiseta particeps* (Adams) was reported by Jackson *et al.* (2013), while the fourth species, *Aedes schizopinax*, is documented here.

Aedes schizopinax was described by Dyar, (1929) from larvae collected at Story Creek railway crossing in central Montana. The specific name (Greek: divided disc) derives from the sclerotised tergite, the saddle or disc on the terminal abdominal segment X of the larva. In contrast to the larvae of the sympatric and related *Aedes hexodontus* Dyar, *Ae. nevadensis* Chapman & Barr, and *Ae. punctor* (Kirby), the saddle does not completely surround the segment, leaving a noticeable gap ventrally. The species has since been collected from other subalpine regions of Montana and from similar habitats in Idaho, Oregon, California, Wyoming, Utah, Nevada and New Mexico (Darsie and Ward 2005). In Canada, the only other collections are of larvae from Morleyville Settlement and Calgary, Alberta, 36 years ago (Enfield 1977). We retain the generic names used in Wood *et al.* (1979), noting that some authors have replaced *Aedes* with the subgeneric name *Ochlerotatus* for all the *Aedes* species named here.

The five larvae (preserved in 80% ethanol) that we examined match the description in Wood *et al.* (1979). No adults were reared. The symmetrically arranged head setae 7 and 5C had two and three branches, respectively, and all branches of the prothoracic setae 2 and 3P were as sturdy as setae 1P. The mesothoracic setae 1M had three strong branches, and these, with the more obvious evenly spaced teeth on the pecten and twenty-five or more pointed comb scales, clearly identify the species as *Ae. schizopinax*.

The four anal papillae of the larva are drawn in Plate 45 of Wood *et al.* (1979), with the dorsal pair slightly longer than the ventral ones. In the fourth and final instar larva that we measured, the anal segment AX was 0.61mm long and the dorsal two papillae were slightly longer than the ventral pair (0.38: 0.33mm) and about the same length as the saddle. Carpenter and LaCasse (1955) in Fig. 188 and Darsie and Ward (2005) in Fig. 772 show the dorsal and ventral papillae to be the same length. The reason for the difference in lengths is not known, but it occurs in species in several genera, always with the dorsal longer than the ventral pair. The unequal length of the dorsal and ventral papillae is used by Wood *et al.* (Fig. 199) to separate *Aedes increpitus* Dyar from *Ae. stimulans* (Walker). However, the size of the papillae is known to vary inversely with the salinity of the environment (Phillips and Meredith 1969), so the consistency of the difference in length of the papillae deserves further study. The seta on the side of the saddle differed from that illustrated in Plate 45 of Wood *et al.* (1979)

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Figure 1. Grassy pool near Sparwood (49° 44' 10.28"N, 114° 53' 5.45"W; elevation: 1124m), the first known site for *Aedes schizopinax* in British Columbia.

being bifid rather than unbranched, but this matches the description of the Californian specimen in Fig. 772 of Darsie and Ward (2005).

Sparwood is in the Montane Spruce biogeoclimatic zone (B.C. Ministry of Forests 2013). It is approximately 160 km southwest of Morleyville settlement, Alberta, and 400km northwest of Story Creek, Montana, but all three localities are at elevations over 1000m. We expect that *Ae. schizopinax* will be found in similar habitats in other parts of southeastern B.C.

There are at least 82 species of mosquitoes in Canada (Thielman and Hunter 2007). Because of the biogeographical history of B.C. and its rich diversity of habitats, more than half of these species occur in the province. We are confident that several more species will be identified, and in the meantime, we hope to collect and rear adult *Ae. schizopinax* in Sparwood; Adults are seldom observed, and little is known of their biology.

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Symposium Abstracts: The Rise and Fall of the Honeybee

Entomological Society of British Columbia Annual General Meeting, PacificForestry Centre, Victoria, B.C., Nov. 1-2, 2013

Note: There was a total of eight papers presented in this symposium. We were able to obtain abstracts from six of the authors.

SuperBoost

H. Borden, *Contech Enterprises Inc., Delta, B.C. www.contech-inc.com*

SuperBoost is a commercial product based on the 10-component fatty-acid ester honeybee brood pheromone. One hundred eighty milligrams of the non-volatile synthetic pheromone are deployed in a small plastic pouch held at the level of the brood comb in a rigid plastic holder. The pheromone exudes through a permeable plastic membrane at the rate of 0.5–2.0 mg/d. When SuperBoost was placed in colonies, the ratio of pollen to non-pollen foragers changed significantly in favour of the former for five weeks, and foragers returned to the hive with significantly heavier pollen loads than did bees returning to untreated control colonies. Compared to untreated control colonies, colonies treated for two consecutive five-week periods during spring build-up consumed more pollen-substitute diet, had more brood comb and more bees, and produced more splits.

In three studies in which colonies were treated with SuperBoost near the beginning of nectar flow, treated colonies produced 24–87% more honey than untreated control colonies. The effect is hypothesized to be caused by higher numbers of bees in treated colonies. In a fourth study, in which colonies were treated at the beginning of July, there was no significant increase in honey production. When colonies were treated during fall feeding, the results were similar to those obtained during spring build-up. Package bee colonies treated six times in the year starting on 30 April, when colonies were established, had 2.7-times greater survival than untreated colonies.

Although SuperBoost is sold elsewhere in the world, it is not available in Canada, where it has been declared an unregistered veterinary drug.

Re-opening Pandora's hive: The risks of importing honeybee packages from the U.S. to Canada

C. Culley, *Capital Region Beekeepers' Association, Victoria, B.C.*

In 1987, in response to the outbreak in the U.S. of two parasitic mites (honeybee tracheal mite, *Acarapis woodi*, and varroa mite, *Varroa destructor*), Agriculture and Agri-Food Canada closed the border to the importation of honeybees (*Apis mellifera*) from the continental U.S. Importations of honeybee queens were allowed from Hawaii in 1993. Following the Canadian Food Inspection Agency's (CFIA) 2003 risk assessment, the Agency maintained the import ban on honeybee packages, but in 2004 allowed the importation of honeybee queens from the U.S.

In 2013, because requests for import permits continue to be received, the Animal Health Risk Assessment (AHRA) unit of the CFIA conducted a risk assessment to provide scientific information and advice in support of the Canadian National Animal Health Program for the development of import policy. The CFIA's Animal Import/Export Division asked the AHRA to update and assess the likelihood of biological hazards spreading or becoming established in Canada, and their likely consequences as a result of the importation of honeybee packages from the U.S.

The Capital Region Beekeepers' Association (CRBA) sent a letter to the Minister of Agriculture and Agri-Food requesting that the border remain closed to honeybee packages due to many disease risks. Of the risks identified by the CRBA, only four were recognized by the CFIA: Africanized honeybee (AHB), antibiotic-resistant American foulbrood (AFB, resistant to oxytetracycline [rAFB]), small hive beetle (SHB), and amitraz-resistant *Varroa* mite (acaricide-resistant [rVAR]). The CFIA considered the following disease agents "not

hazards": *Tropilaelaps* (not currently found in U.S., but could appear at any time and be spread with industrial movements of bees), *Apocephalus borealis* (insufficient research), and a wide variety of viruses, also thoroughly distributed by industrial movements. Several disease agents could also infect our native pollinators.

The CRBA does not accept the levels of risk established in the report, due to many uncertainties that were factored in. Lack of research is not a good reason for lower risk. This risk-assessment document was a literature review, which is useful; however, it makes it only more clear that more research needs to be done before risks can be properly assessed.

Trends in managed pollinators and resurgence of urban beekeeping

H. Clay, *Urban Bee Network, B.C.*

Honey has been a sought-after natural sweetener for centuries. Since the advent of the modern movable-frame hive, large-scale beekeeping for honey production has become an important sector of rural Canadian agriculture. Throughout the past century, whenever war or recession has posed a threat to food supply, urban beekeeping has increased. The highest number of beekeepers ever recorded in Canadian history was during the sugar rationing period of the Second World War.

Fluctuations have occurred according to whether beekeeping was profitable (good honey prices, opportunities for pollination service rental) or not profitable (low honey prices, honeybee colony losses, high cost of replacement bees). Honeybees are also important pollinators of agricultural crops, and colony numbers increased after research showed the importance of bees for improving crop production. Colony increase occurred in two cycles: from 1960 to 1985, pollination service expansion was for tree fruit and berry crops, and since 1991 the demand for pollination services has been driven by the canola seed industry. Other managed pollinators such as alfalfa leafcutter bees, bumble bees and mason bees offer some potential for greenhouse-crop pollination and as complementary pollinators, but their availability and short flight range have been limiting factors for large-scale crops.

Canada's beekeeping industry was significantly affected by the arrival of a new parasite, *Varroa* mite, in 1989. Beekeeper numbers dropped steadily for two decades from their peak in 1985. Recently, there has been a measurable upward trend of urban beekeepers and colony numbers following the Global Financial Crisis (2008–2010) and its accompanying recession. This period also corresponded with a surge in media interest and public awareness of honeybee colony losses. Many consumers are concerned about the plight of pollinators and want to obtain food locally, so demand for urban bees is high. With recent changes in city bylaws, it is clear that the trend to urban agriculture and urban beekeeping is here to stay.

Native pollinators and the diversity of bees

C. S. Sheffield, *Royal Saskatchewan Museum, Regina, SK*

The last decade has revealed that we are so reliant on one species, the European honeybee (*Apis mellifera* L.), for crop production via pollination that we now face a possible food-security issue with its continuing decline. Our best hopes may not lie in putting all our research efforts and resources into helping this charismatic species, but in also including other native bee species into the crop-pollination equation.

Canada has over 800 species of bees, and many show much potential as managed and encouraged pollinators. Wild bees can be encouraged to live in many terrestrial habitats, including agricultural ones, by conserving and providing ample pollen and nectar resources and nesting sites and habitats. Cavity-nesting bees, primarily the family *Megachilidae*, show great potential as alternative managed pollinators, because many species accept artificial nesting sites (i.e., nesting blocks) and show strong preferences for some crop plants. As well, combinations of crop and non-crop plants that flower in sequence can be used to promote bee-population growth in crop systems. By considering what bees need, and then providing it, we can supplement pollination services. In addition, most of the things that we do to help native bees will also benefit honeybees, which allows us to meet concerns for all pollinators.

Colony collapse disorder, farm chemicals, and pollinator declines

P. van Westendorp, *British Columbia Ministry of Agriculture, Abbotsford, B.C.*

Since 2000, pollinator declines have been reported in many parts of the world. This decline has not been limited to honeybees (*Apis mellifera*), but also to other Hymenoptera pollinators. French beekeepers first reported high losses of apparently healthy colonies near corn and potato plantings. Neither of these crops is of interest to bees as forage sources. Similar losses were reported by beekeepers in other European countries, which led to the suspicion of a link between colony losses and the insecticides used on these crops.

In the late 1980s, the neonicotinoid insecticides were introduced in Europe; since then, formulations have been registered in more than 120 countries. The neonicotinoids mimic the natural plant derivative of nicotine, which is characterized by its rapid knock-down effect, short efficacy period, and rapid breakdown. On the other hand, neonicotinoids have proven highly effective at disrupting an insects central nervous system, as well as for their systemic action and high persistence in the soil. Furthermore, neonicotinoids display low to moderate toxicity to mammals, affecting only their peripheral nervous systems.

In the fall of 2006, U.S. beekeepers reported catastrophic losses of apparently healthy colonies without the identification of the causal agent(s). The phenomenon was dubbed "colony collapse disorder" (CCD). The extent of the losses was so significant that it seriously jeopardized the production of a range of pollinator-dependent crops, most notably almonds. Despite intense research efforts, no definitive causal agent of CCD has been identified. It is generally accepted that CCD is caused by various biotic and abiotic factors. In particular, mite parasitism of the obligate, host-specific *Varroa destructor* has had a highly destructive impact on honeybees. The situation has been exacerbated by bee viruses vectored by the *Varroa* mite. Other factors include management, bee genetics, dietary deficiencies, and exposure to farm chemicals. However, until now, there has been no scientific evidence of a direct link between CCD and neonicotinoid insecticides.

Since the initial introduction of neonicotinoids, a wide range of systemic formulations have been developed for use in numerous crops. Acute toxicity to insects has never been in dispute, but due to their persistence in the environment, it is believed that neonicotinoids may cause pollinator declines due to their chronic exposure at sub-lethal levels, resulting in irreparable nerve damage. An increasing body of evidence shows that chronic exposure at sub-lethal levels results in memory loss, changes in foraging and reproductive behavior, and a suppression of the insect's immune response system.

While unequivocal scientific evidence of the impact of neonicotinoids on pollinators has not yet been produced, the environmental consequences of the constant application of farm chemicals are highlighted by the way these products are marketed and promoted. From the 1960s onwards, integrated pest management (IPM) programs were developed for most crops and considered the use of any chemical or drug only when monitoring data support the need for the chemical or drug. However, today, many farm chemicals are applied prophylactically, regardless of need. Neonicotinoid insecticides are applied to 100% of corn seed and 50% of soy seeds. Until recently, farmers had to pay a higher price for untreated corn seed. The departure from IPM principles is of great concern, because they are replaced by a management system that incorporates the indiscriminate and chronic use of chemicals into the environment, without clear evidence on the long-term impact these chemicals have on non-target organisms.

Decision-making by the Canadian Food Inspection Agency

H. Higo, *Canadian Food Inspection Agency, Surrey, B.C.*

The 2013 risk analysis on the importation of bulk honeybees from the continental U.S. was released by the Canadian Food Inspection Agency (CFIA) on 25 October 2013. The CFIA uses a standard protocol for evaluating potential risks of imports from other countries. This presentation outlines the general risk assessment protocol and details how this protocol was applied in the recent honeybee risk assessment.

The CFIA considered four disease and pest issues to be hazards: the Africanized honeybee, antibiotic-resistant American foulbrood, small hive beetle, and acaricide-resistant *Varroa* mites. These hazards were all estimated to be moderate or low-to-moderate risks. Because the risks had not changed significantly since the last risk assessment in 2003, no change in the importation status of bulk honeybees from the continental U.S. was recommended.

Bee integrated pest management

H. Higo, *Canadian Food Inspection Agency, Surrey, B.C.*

Honeybee colony losses have increased significantly in recent years, from an average loss of 10–15% prior to 2006 to 30% or more since then. The causes of these elevated colony losses appear to be multi-factorial, including diseases and pests (such as the *Varroa* mite, *Nosema* disease, and viruses transmitted by *Varroa* mites), reduced pollen and nectar availability with habitat loss and mono-cropping agriculture systems, and exposure to pesticides or other environmental factors in the field and in the hive. Integrated pest management (IPM) of *Varroa* mites and other diseases in the hive without relying heavily on harsh chemicals may help to reduce the honeybee decline.

This presentation outlines a novel project using proteomics—a potential new weapon in the IPM toolbox—to select for specific honeybee behaviours that combat *Varroa* mites and other diseases. Several honeybee antennal proteins were shown in a previous project to be closely associated with worker hygienic behaviour, in which workers selectively remove diseased or infested pupae from the colony before the disease or mite has a chance to reproduce. Beginning in 2011, we sampled and tested commercial colonies across western Canada for hygienic behaviour. Cooperating beekeepers allowed us to remove selected queens, and going forward we used a two-pronged selection protocol to breed three generations of bees, either using proteomics or traditional, laborious field tests for disease-resistance.

Early results appear promising, but final results from the 2013 mite and bacterial challenges of the F3 generation are still being evaluated. As well, economic evaluations are underway in Manitoba and Alberta, as are practical evaluations of F3 queens by commercial cooperators across western Canada. Results will be released in the summer of 2014, and proteomic testing could soon be a new IPM tool available to beekeepers.

This project involved researchers from the University of British Columbia (Leonard Foster, Marta Guarna, Amanda van Haga, Miriam Bixby), University of Manitoba (Rob Currie), Agriculture and Agri-Food Canada (Stephen Pernal, Abdullah Ibrahim, Shelley Hoover, Adony Melathopoulos) and bee breeders Liz Huxter and Heather Higo. Funding was provided by Genome Canada, Genome BC, Genome Alberta, Agriculture and Agri-Food Canada, University of British Columbia, University of Manitoba, and the B.C. Honey Producers Association.

Presentation Abstracts

Entomological Society of British Columbia Annual General Meeting, PacificForestry Centre, Victoria, B.C., Nov. 1-2, 2013

Phylogenetics and natural history of the subfamily Tryphoninae (Hymenoptera: Ichneumonidae)

A. Bennett, *Canadian National Collection of Insects, Agriculture & Agri-Food Canada, Ottawa, Ontario*

The Tryphoninae are a group of ectoparasitoid wasps that parasitize sawfly and Lepidoptera larvae. There are 1252 species in 59 genera worldwide. A morphological phylogenetic analysis was performed to examine their relationships. This analysis permits discussion of the evolution of adaptive characters and host associations.

Bee talk: Do honeybees use the Earth magnetic field as a reference to align their waggle dance?

V. Lambinet, M. Hayden, M. Bieri and G. Gries, *Departments of Biological Sciences and Physics, Simon Fraser University, Burnaby, B.C.*

Waggle-dancing honeybees recruit hive mates to a food source. Directional information is encoded in the angle between the waggle run line of the dancer and a reference line, predicted to be gravity or the geomagnetic field (GMF). Canceling the GMF around hives revealed no effect on the dancer's recruiting success.

***De novo* transcriptome of *Megastigmus spermotrophus*: Hunting for mechanisms of host manipulation**

A. Paulson, S. Perlman, P. von Aderkas, *Department of Biology, University of Victoria, Victoria, B.C.*

Megastigmus spermotrophus (Hymenoptera: Torymidae) is a seed parasite of Douglas-fir, *Pseudotsuga menziesii*. Three highly expressed venom transcripts from females were identified in the transcriptome. One of these venoms, aspartylglucosaminidase, has been identified as a major venom constituent of two parasitoid wasps.

Cyberbugs: Military and non-military research and applications

A. Behennah, *1829 Laval Avenue, Victoria, B.C.*

Within the past 20 years, a series of experiments have attempted to hybridize insects with technology for military or security purposes. Hymenoptera were applied to the detection of explosives and land-mines, and electronics implanted into muscle and nerve tissues remade cockroaches, moths, and beetles into remote-controlled bio-robots.

***Drosophila suzukii* in the *D. suzukii* world: Humidity decreases density-dependent competition**

C. Hodson, S. Dhanani, A. Hoi, A. Chubaty and F. Simon, *Department of Biological Sciences, Simon Fraser University, Burnaby, B.C.*

Humidity has been suggested to be important for *Drosophila suzukii* development; However, how it mediates competition has not been described previously. An examination of density-dependent competition under variation in humidity of *D. suzukii* suggests that high humidity reduces the consequences of competition at high densities.

Transgenerational Effects on Disease Resistance in an Insect Herbivore

G. Olson and J. Cory, *Department of Biological Sciences, Simon Fraser University, Burnaby, B.C.*

The western tent caterpillar undergoes dramatic population cycles that coincide with viral epizootics. Our research investigates how changes in dietary factors related to density altered disease resistance over two generations. Contrary to expectations, our findings indicate that dietary stressors may enhance disease resistance, leading to more disease-resistant populations.

Web-reduction behaviour in black widows: A story of attraction, courtship, manipulation, and rivalry

C. Scott, D. Kirk, S. McCann and G. Gries, *Department of Biological Sciences, Simon Fraser University, Burnaby, B.C.*

Western black widow females attract males with a silk-borne sex pheromone. During courtship, males often engage in 'web-reduction'—dismantling and bundling up parts of the female's web. We present data from a field experiment demonstrating that web-reduction functions to decrease web attractiveness, thereby limiting the arrival of male competitors.

How to kill a parasite: Transcriptional responses in a *Drosophila* defensive symbiosis

P. Hamilton, J. Leong, B. Koop and S. Perlman, *Department of Biology, University of Victoria, Victoria, B.C.*

Symbioses of insects can be critical to host defense. *Drosophila neotestacea* is defended against a nematode parasite by the bacterium *Spiroplasma*, but the mechanism of this defense is unknown. Transcriptome sequencing in this system shows that the production of toxins by *Spiroplasma* is the most likely cause of defense.

Population dynamics of a tritrophic food chain in a warming world: A modeling approach

M. Orobko, F. Simon and B. Roitberg, *Department of Biological Sciences, Simon Fraser University, Burnaby, B.C.*

We simulated varying levels of heat waves, along with predicted mean temperature increases, in a model of a tritrophic food chain with organisms whose performances were temperature-dependent. We found that heat waves could lead to an increased risk of extinction in these communities.

Exploring the temporal and dose-dependent immune response to baculovirus in an insect

J. Scholefield, I. Shikano, V. Fung, and J. Cory, *Department of Biological Sciences, Simon Fraser University, Burnaby, B.C.*

We exposed the cabbage looper, *Trichoplusia ni*, to different doses of a baculovirus, and measured the haemocyte response at different time periods following exposure. Changes in haemocyte type and density could affect within-host competition with other pathogens. The changes have important evolutionary consequences for the evolution of virulence and insect population management.

How do entomopathogenic fungi and parasitoids interact over a long term to control aphids in greenhouses?

Y. Norouzi, J. Cory and D. Gillespie, *Department of Biological Sciences, Simon Fraser University, Burnaby, B.C., and Agriculture & Agri-Food Canada, Agassiz, B.C.*

Beauveria bassiana (strain GHA) in the commercialized form, BotaniGard, had a positive interaction with a parasitoid *Aphidius matricariae*. In the six-week period, the use of both biocontrol agents together resulted in fewer aphids and more parasitoid mummies on the plants than any of those biocontrol agents alone.

A social raptor exploits the absconding response of Neotropical social wasps in order to prey on their nests

S. McCann, O. Moeri, T. Jones, C. Scott, G. Khaskin, R. Gries, S. O'Donnell and G. Gries, *Department of Biological Sciences, Simon Fraser University, Burnaby, B.C. and Department of Biodiversity, Earth and Environmental Science, Drexel University, Philadelphia, PA, USA.*

Red-throated Caracaras are falconid raptors that specialize in the brood of social wasps. We tested the hypothesis that they use repellents to fend off wasps by chemically analyzing the birds' feather and feet and video-recording nest attacks. We conclude that caracaras use behavioural manipulation to subdue their prey.

***Anopheles gambiae* alters blood-feeding behavior in response to a host protected with the new repellent 3c(3,6)**

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Anopheles gambiae is a vector of *Plasmodium* spp., which cause malaria. We evaluated bloodhost-seeking behaviour of *A. gambiae* when the host is protected by the

chemical 3c(3,6). We compared our results with DEET and found that 3c(3,6) may be an effective new chemical to repel *A. gambiae*.

We can't be friends: Interspecific aggressive competitive behaviour of *Drosophila suzukii* and *Drosophila melanogaster* females when forced to share a common resource

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Drosophila suzukii differs from all other *Drosophila* by ovipositing in fresh rather than rotting fruits (Hauser 2011). When forced to utilize the same resources as *D. melanogaster*, *D. suzukii* performs poorly (Stemberger, pers comm). This study explores one aspect of competitive behaviours between these two species.

Insect community dynamics in a high-Arctic ecosystem

S. Robinson and G. Henry, *University of British Columbia, Vancouver, B.C.*

Climate change is expected to alter the dynamics of high-Arctic ecosystems. Plant communities have been studied in many high-Arctic ecosystems, but there are relatively few studies of insect communities, and even fewer on how these communities change throughout the short snow-free season. Having this information is important in the context of pollination services to flowering plants. During the summer of 2012, we conducted bowl trapping and hand-netting every two days, in order to survey the overall insect community as well as important floral visitors, at Alexandra Fiord, Ellesmere Island, Nunavut. The dominant floral visitors were primarily dipterans: *Syrphidae* of the genus *Eupeodes*, *Muscidae* of the genera *Phaonia* and *Drymeia*. Arctic bumblebees (*Bombus polaris*) were also found, but at nowhere near the frequency of the dipterans. Both families of dipterans were also found to visit during distinctly different times of the snow-free season. We present some of our preliminary findings on how this community changes throughout the season, and what changes in visitation may mean for a warming arctic.

Pheromone-mediated defensive behaviour of *Dolichvespula maculata*.

S. Ibarra, S. McCann, R. Gries, H. Zhai, and G. Gries, *Department of Biological Sciences, Simon Fraser University, Burnaby, B.C.*

We tested pheromone-mediated defensive behavior by *Dolichovespula maculata* hornets in response to venom-gland extracts from conspecifics. In venom-gland extracts of *D. maculata*, we identified seven components that, when tested as a synthetic blend, induced defensive behavior similar to venom-gland extracts.

Patch-size and temperature-interaction effects on the predation of pea aphids (*Acrythosiphon pisum*) by the Asian Ladybird beetle, *Harmonia axyridis*

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In order to study the combined effects of rearing temperature, foraging patch size, and foraging temperature on the predation rate of pea aphids by the Asian Ladybird beetle, a 2x2x2 factorial design experiment was done using rearing temperature, foraging temperature, and arena size as variables. Exposure temperature had the strongest effect on predation rate, whereas a strong interaction between exposure temperature and arena size was observed.

Effects of poplar phenolics on the fitness and behaviour of *Chaitophorus* aphids

A. Wong, P. Constabel and S. Perlman, *Department of Biology, University of Victoria, Victoria, B.C.*

Effects of phenolic secondary metabolites on phloem feeders was investigated using transgenic poplar with high tannins and low phenolic glycosides in bioassays with specialist *Chaitophorus* aphids. Aphids had higher fecundity on transgenic plants, but preferred wild-type tissue. Phenolic glycosides were identified in aphid extracts providing support for their presence in phloem and ingestion during aphid feeding.

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